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ALTITUDE DEVELOPMENTAL TESTING OF THE J-2 ROCKET ENGINE IN PROPULSION ENGINE TEST CELL (J-4) (TEST J4-1801-20)

N. S. Dougherty, Jr.

ARO, Inc.

June 1968

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LARGE ROCKET FACILITY
ARNOLD ENGINEERING DEVELOPMENT CENTER
AIR FORCE SYSTEMS COMMAND
ARNOLD AIR FORCE STATION, TENNESSEE

NOTICES

ALTITUDE DEVELOPMENTAL TESTING OF THE J-2 ROCKET ENGINE IN PROPULSION ENGINE TEST CELL (J-4) (TEST J4-1801-20)

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FOREWORD

The work reported herein was sponsored by the National Aeronautics and Space Administration (NASA), Marshall Space Flight Center (MSFC), under System 921E, Project 9194.

The results of the tests presented were obtained by ARO, Inc. (a subsidiary of Sverdrup & Parcel and Associates, Inc.), contract operator of the Arnold Engineering Development Center (AEDC), Air Force Systems Command (AFSC), Arnold Air Force Station, Tennessee, under Contract AF40(600)-1200. Program direction was provided by NASA/MSFC; engineering liaison was provided by North American Rockwell Corporation, Rocketdyne Division, manufacturer of the J-2 rocket engine, and McDonnell Douglas Corporation, Douglas Aircraft Company, Missile and Space Systems Division, manufacturer of the S-IVB stage. The testing reported herein was conducted on December 14, 1967, in Propulsion Engine Test Cell (J-4) of the Large Rocket Facility (LRF) under ARO Project No. KA1801. The manuscript was submitted for publication on April 11, 1968.

This technical report has been reviewed and is approved.

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ABSTRACT

Five firings of the Rocketdyne J-2 rocket engine were conducted in Test Cell J-4 of the Large Rocket Facility. The firings were accomplished during test period J4-1801-20 at pressure altitudes ranging from 104,000 to 112,000 ft at engine start to evaluate engine starting characteristics at the minimum main oxidizer valve sequence ramp limit and reduced fuel pump net positive suction head. These firings were in support of the S-II vehicle application for Saturn flights AS 502 and AS 503. Engine components were thermally conditioned to predicted values for the S-II interstage/engine environment. Satisfactory engine operation was obtained. The accumulated firing duration was 56.22 sec.

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I. ILLUSTRATIONS

II. TABLES (Continued)

NOMENCLATURE

A	Area, in.^{2}
ASI	Augmented spark igniter
ES	Engine start, designated as the time that helium control and ignition phase solenoids are energized
GG	Gas generator
MOV	Main oxidizer valve
STDV	Start tank discharge valve
t_0	Defined as the time at which the opening signal is applied to the start tank discharge valve solenoid
VSC	Vibration safety counts, defined as the time at which engine vibration was in excess of 150 g rms in a 960- to 6000-Hz frequency range

SUBSCRIPTS

f	Force
m	Mass
t	Throat

SECTION I
INTRODUCTION

Testing of the Rocketdyne J-2 engine (S/N's J-2052 and J-2047) using an S-IVB battleship stage has been in progress since July 1966 at AEDC in support of the J-2 engine application on the Saturn IB and Saturn V launch vehicles for the NASA Apollo Program. The five firings reported herein were conducted during test period J4-1801-20 on December 14, 1967, in Propulsion Engine Test Cell (J-4) (Figs. 1 and 2, Appendix I) of the Large Rocket Facility (LRF) to evaluate J-2 engine S-II/S-V starting characteristics using: (1) reduced fuel pump net positive suction head (NPSH) values, (2) a heavier-turbine-wheel configuration oxidizer turbopump, and (3) the main oxidizer valve sequenced at the minimum S-II ramp limit ($1350\,^{+10}_{-20}$ msec). These firings were accomplished at pressure altitudes ranging from 104,000 to 112,000 ft (geometric pressure altitude, Z, Ref. 1) at engine start and with selected engine components conditioned to predicted S-II interstage/engine temperatures.

This test period concluded a series of J-2 engine S-II/S-V investigations at reduced fuel pump NPSH values using engine S/N J-2047 in the 225,000-lb_f-thrust configuration. Data collected to accomplish the test objectives are presented herein. Copies of all data obtained during this test have been previously supplied to the sponsor, and copies are on file at AEDC. The results of previous tests conducted November 27 through December 7, 1967 (Tests J4-1801-17, 18, and 19) are presented in Ref. 2.

SECTION II
APPARATUS

2.1 TEST ARTICLE

The test article was a J-2 rocket engine (Fig. 3) designed and developed by Rocketdyne Division of North American Rockwell Corporation. The engine uses liquid oxygen and liquid hydrogen as propellants and has a thrust rating of 225,000 lb_f at an oxidizer-to-fuel mixture ratio of 5.5 An S-IVB battleship stage with flight-type S-IVB stage low pressure propellant supply ducts was used to supply propellants to the engine. A schematic of the battleship stage is presented in Fig. 4.

Listings of major engine components and engine orifices for this test period are presented in Tables I and II, respectively (Appendix II). All engine modifications performed since the previous test period are presented in Table III.

2.1.1 J-2 Rocket Engine

The J-2 rocket engine (Figs. 3 and 5, Ref. 3) features the following major components:

1. Thrust Chamber - The tubular-walled, bell-shaped thrust chamber consists of an 18.6-in.-diam combustion chamber (8.0 in. long from the injector mounting to the throat inlet) with a characteristic length (L*) of 24.6 in., a 170.4-in.^{2} throat area, and a divergent nozzle with an expansion ratio of 27.1. Thrust chamber length (from the injector flange to the nozzle exit) is 107 in. Cooling is accomplished by the circulation of engine fuel flow downward from the fuel manifold through 180 tubes and then upward through 360 tubes to the injector.

2. Thrust Chamber Injector - The injector is a concentric-orificed (concentric fuel orifices around the oxidizer post orifices), porous-faced injector. Fuel and oxidizer injector orifice areas are 25.0 and 16.0 in.^{2}, respectively. The porous material, forming the injector face, allows approximately 3.5 percent of total fuel flow to transpiration cool the face of the injector.

3. Augmented Spark Igniter - The augmented spark igniter unit is mounted on the thrust chamber injector and supplies the initial energy source to ignite propellants in the main combustion chamber. The augmented spark igniter chamber is an integral part of the thrust chamber injector. Fuel and oxidizer are ignited in the combustion area by two spark plugs.

4. Fuel Turbopump - The turbopump is composed of a two-stage turbine-stator assembly, an inducer, and a seven-stage axial-flow pump. The pump is self-lubricated and nominally produces, at rated conditions, a head rise of 35,517 ft (1225 psia) of liquid hydrogen at a flow rate of 8414 gpm for a rotor speed of 26,702 rpm.

5. Oxidizer Turbopump - The turbopump is composed of a two-stage turbine-stator assembly and a single-stage centrifugal pump. The pump is self-lubricated and nominally produces, at rated conditions, a head rise of 2117 ft (1081 psia) of liquid oxygen at a flow rate of 2907 gpm for a rotor speed of 8572 rpm.

6. Gas Generator - The gas generator consists of a combustion chamber containing two spark plugs, a pneumatically operated control valve containing oxidizer and fuel poppets, and an injector assembly. The oxidizer and fuel poppets provide a fuel lead to the gas generator combustion chamber. The high energy gases produced by the gas generator are directed to the fuel turbine and then to the oxidizer turbine (through the turbine crossover duct) before being exhausted into the thrust chamber at an area ratio (A/A_t) of approximately 11.

7. Propellant Utilization Valve - The motor-driven propellant utilization valve is mounted on the oxidizer turbopump and bypasses liquid oxygen from the discharge to the inlet side of the pump to vary engine mixture ratio.

8. Propellant Bleed Valves - The pneumatically operated fuel and oxidizer bleed valves provide pressure relief for the boiloff of propellants trapped between the battleship stage prevalves and main propellant valves at engine shutdown.

9. Integral Hydrogen Start Tank and Helium Tank - The integral tanks consist of a 7258-in.^{3} sphere for hydrogen with a 1000-in.^{3} sphere for helium located within it. Pressurized gaseous hydrogen in the start tank provides the initial energy source for spinning the propellant turbopumps during engine start. The helium tank provides a helium pressure supply to the engine pneumatic control system.

10. Oxidizer Turbine Bypass Valve - The pneumatically actuated oxidizer turbine bypass valve provides control of the fuel turbine exhaust gases directed to the oxidizer turbine in order to control the oxidizer-to-fuel turbine spinup relationship. The fuel turbine exhaust gases that bypass the oxidizer turbine are discharged into the thrust chamber.

11. Main Oxidizer Valve - The main oxidizer valve is a pneumatically actuated, two-stage, butterfly-type valve located in the oxidizer high pressure duct between the turbopump and the main injector. The first-stage actuator positions the main oxidizer valve at the 14-deg position to obtain initial thrust chamber ignition; the second-stage actuator ramps the main oxidizer valve full open to accelerate the engine to main-stage operation.

12. Main Fuel Valve - The main fuel valve is a pneumatically actuated butterfly-type valve located in the fuel high pressure duct between the turbopump and the fuel manifold.

13. Pneumatic Control Package - The pneumatic control package controls all pneumatically operated engine valves and purges.

14. Electrical Control Assembly - The electrical control assembly provides the electrical logic required for proper sequencing of engine components during operation.
15. Primary and Auxiliary Flight Instrumentation Packages - The instrumentation packages contain sensors required to monitor critical engine parameters. The packages provide environmental control for the sensors.

2.1.2 S-IVB Battleship Stage

The S-IVB battleship stage is approximately 22 ft in diameter and 49 ft long and has a maximum propellant capacity of 46, 000 lb of liquid hydrogen and 199, 000 lb of liquid oxygen. The propellant tanks, fuel above oxidizer, are separated by a common bulkhead. Propellant prevalves, in the low pressure ducts (external to the tanks) interfacing the stage and the engine, retain propellant in the stage until being admitted into the engine to the main propellant valves and serve as emergency engine shutoff valves. Propellant recirculation pumps in both fuel and oxidizer tanks are utilized to circulate propellants through the low pressure ducts and turbopumps before engine start to stabilize hardware temperatures near normal operating levels and to prevent propellant temperature stratification. Vent and relief valve systems are provided for both propellant tanks.

Pressurization of the fuel and oxidizer tanks was accomplished by facility systems using hydrogen and helium, respectively, as the pressurizing gases. The engine-supplied gaseous hydrogen and gaseous oxygen for fuel and oxidizer tank pressurization during S-II flight were routed to the respective facility venting systems during all five firings. The gaseous hydrogen repressurant flow was programmed off at $t_0 + 7.5$ sec during each firing.

2.2 TEST CELL

Test Cell J-4, Fig. 2, is a vertically oriented test unit designed for static testing of liquid-propellant rocket engines and propulsion systems at pressure altitudes of 100, 000 ft. The basic cell construction provides a 1. 5-million-lb_f-thrust capacity. The cell consists of four major components (1) test capsule, 48 ft in diameter and 82 ft in height, situated at grade level and containing the test article; (2) spray chamber, 100 ft in diameter and 250 ft in depth, located directly beneath the test capsule to provide exhaust gas cooling and dehumidification; (3) coolant water, steam, nitrogen (gaseous and liquid), hydrogen (gaseous and liquid), and liquid oxygen and gaseous helium storage and delivery

systems for operation of the cell and test article; and (4) control building, containing test article controls, test cell controls, and data acquisition equipment. Exhaust machinery is connected with the spray chamber and maintains a minimum test cell pressure before and after the engine firing and exhausts the products of combustion from the engine firing. Before a firing, the facility steam ejector, in series with the exhaust machinery, provides a pressure altitude of 100,000 ft in the test capsule. A detailed description of the test cell is presented in Ref. 4.

The battleship stage and the J-2 engine were oriented vertically downward on the centerline of the diffuser-steam ejector assembly. This assembly consisted of a diffuser duct (20 ft in diameter by 150 ft in length), a centerbody steam ejector within the diffuser duct, a diffuser insert (13.5 ft in diameter by 30 ft in length) at the inlet to the diffuser duct, and a gaseous nitrogen annular ejector above the diffuser insert. The diffuser insert was provided for dynamic pressure recovery of the engine exhaust gases and to maintain engine ambient pressure altitude (attained by the steam ejector) during the engine firing. The annular ejector was provided to suppress steam recirculation into the test capsule during steam ejector shutdown. The test cell was also equipped with (1) a gaseous nitrogen purge system for continuously inerting the normal air in-leakage of the cell; (2) a gaseous nitrogen repressurization system for raising test cell pressure, after engine cutoff, to a level equal to spray chamber pressure and for rapid emergency inerting of the capsule; and (3) a spray chamber liquid nitrogen supply and distribution manifold for initially inerting the spray chamber and exhaust ducting and for increasing the molecular weight of the hydrogen-rich exhaust products.

An engine component conditioning system was provided for temperature conditioning engine components. The conditioning system utilized a liquid hydrogen-helium heat exchanger to provide cold helium gas for component conditioning. Engine components requiring temperature conditioning were the thrust chamber, crossover duct, main oxidizer valve second-stage actuator, and start tank discharge valve. Cold helium was routed internally through the crossover duct and tubular-walled thrust chamber, and ambient-temperature helium was used to warm the main oxidizer valve and the start tank discharge valve. The desired main oxidizer valve second-stage actuator temperatures were obtained by varying pre-fire propellants-in-engine time.

2.3 INSTRUMENTATION

Instrumentation systems were provided to measure engine, stage, and facility parameters. The engine instrumentation comprised

(1) flight instrumentation for the measurement of critical engine parameters and (2) facility instrumentation which was provided to verify the flight instrumentation and to measure additional engine parameters. The flight instrumentation was provided and calibrated by the engine manufacturer; facility instrumentation was initially calibrated and periodically recalibrated at AEDC. Appendix III contains a list of all measured test parameters and the locations of selected sensing points.

Pressure measurements were made using strain-gage-type pressure transducers. Temperature measurements were made using resistance temperature transducers and thermocouples. Oxidizer and fuel turbopump shaft speeds were sensed by magnetic pickup. Fuel and oxidizer flow rates to the engine were measured by turbine-type flowmeters which are an integral part of the engine. The propellant recirculation flow rates were also monitored with turbine-type flowmeters. Vibrations were measured by accelerometers mounted on the oxidizer injector dome and on the turbopumps. Primary engine and stage valves were instrumented with linear potentiometers and limit switches.

The data acquisition systems were calibrated by (1) precision electrical shunt resistance substitution for the pressure transducers and resistance temperature transducer units; (2) voltage substitution for the thermocouples; (3) frequency substitution for shaft speeds and flowmeters; and (4) frequency-voltage substitution for accelerometers.

The types of data acquisition and recording systems used during this test period were (1) a multiple-input digital data acquisition system (MicroSADIC®) scanning each parameter at 40 samples per second and recording on magnetic tape, (2) single-input, continuous-recording FM systems recording on magnetic tape, (3) photographically recording galvanometer oscillographs, (3) direct-inking, null-balance potentiometer-type X-Y plotters and strip charts, and (5) optical data recorders. Applicable systems were calibrated before each test (atmospheric and altitude calibrations). Television cameras, in conjunction with video tape recorders, were used to provide visual coverage during an engine firing, as well as for replay capability for immediate examination of unexpected events.

2.4 CONTROLS

Control of the J-2 engine, battleship stage, and test cell systems during the terminal countdown was provided from the test cell control room. A facility control logic network was provided to interconnect the engine control system, major stage systems, the engine safety cutoff system, the observer cutoff circuits, and the countdown sequencer. A

schematic of the engine start control logic is presented in Fig. 6. The sequence of engine events for a normal start and shutdown is presented in Figs. 7a and b. Two control logics for sequencing the stage prevalves and recirculation systems with engine start for simulating engine flight start sequences are presented in Figs. 7c and d.

SECTION III
PROCEDURE

Pre-operational procedures were begun several hours before the test period. All consumable storage systems were replenished, and engine inspections, leak checks, and drying procedures were conducted. Propellant tank pressurants and engine pneumatic and purge gas samples were taken to ensure that specification requirements were met. Chemical analysis of propellants was provided by the propellant suppliers. Facility sequence, engine sequence, and engine abort checks were conducted within a 24-hr time period before an engine firing to verify the proper sequence of events. Facility and engine sequence checks consisted of verifying the timing of valves and events to be within specified limits; the abort checks consisted of electrically simulating engine malfunctions to verify the occurrence of an automatic engine cutoff signal. A final engine sequence check was conducted immediately preceding the test period.

Oxidizer dome, gas generator oxidizer injector, and thrust chamber jacket purges were initiated before evacuating the test cell. After completion of instrumentation calibrations at atmospheric conditions, the test cell was evacuated to approximately 0.5 psia with the exhaust machinery, and instrumentation calibrations at altitude conditions were conducted. Immediately before loading propellants on board the vehicle, the cell and exhaust-ducting atmosphere was inerted. At this same time, the cell nitrogen purge was initiated for the duration of the test period, except for the engine firing. The vehicle propellant tanks were then loaded, and the remainder of the terminal countdown was conducted. Temperature conditioning of the various engine components was accomplished as required, using the facility-supplied engine component conditioning system. Engine components that required temperature conditioning were the thrust chamber, the crossover duct, main oxidizer valve second-stage actuator, and start tank discharge valve. Table V presents the engine purges and thermal conditioning operations during the terminal countdown and immediately following each engine firing.

SECTION IV
RESULTS AND DISCUSSION

4.1 TEST SUMMARY

Five firings of the J-2 rocket engine S/N J-2047 were conducted on December 14, 1967, during test period J4-1801-20 for a total accumulated firing duration of 56.22 sec. These firings were in support of the S-II vehicle application for Saturn flights AS 502 and AS 503. Testing was accomplished at pressure altitudes ranging from 104,000 to 112,000 ft at engine start and with selected engine components conditioned to predicted S-II interstage/engine temperatures.

Test objectives were satisfactorily met during all five firings despite slightly colder-than-desired main oxidizer valve second-stage actuator temperatures at engine start for firings 20A, 20B, and 20C. The main oxidizer valve was orificed[1] for this test period to provide a dry-sequence second-stage ramp time of 1350 $^{+10}_{-20}$ msec, the minimum limit for an S-II configuration engine. Satisfactory engine operation was obtained. A summary of test requirements and results is presented in Table V. Start and shutdown transient operating times for selected engine valves are presented in Table VI. Figure 8 shows engine start conditions for turbopump inlets, the start tank, and the helium tank.

Specific test objectives and a brief statement of results are presented below:

Firing	Test Objectives	Results
20A	To evaluate the effect of heavier oxidizer turbine wheels on the engine start transient at minimum starting energy and warmest main oxidizer valve actuator temperature at the minimum S-II sequence ramp limit. To evaluate fuel pump operation at reduced NPSH value.	Heavier turbine wheels apparently had an insignificant effect on start transient characteristics. Main oxidizer valve ramping movement began very early before oxidizer dome prime. The fuel pump flow approached within 450 gpm of stall inception line at t_0 + 1.83 sec. There were no indications of significant fuel pump cavitation at an NPSH of 230 ft.

[1]Nonthermostatic orificed S-II main oxidizer valve.

Firing	Test Objectives	Results
20B	To evaluate the effect of heavier oxidizer turbine wheels on the engine start transient at start tank pressure of 1200 psia and temperature of -200°F and warmest main oxidizer valve actuator temperature at the minimum S-II sequence ramp limit. To evaluate fuel pump operation at reduced NPSH value.	The effect of heavier oxidizer wheels was apparently insignificant. Main oxidizer valve ramp time was 1.691 sec, fastest to date at AEDC. The fuel pump flow approached within 475 gpm of the stall inception line at t_0 + 1.85 sec. There were no indications of significant fuel pump cavitation at an NPSH of 230 ft.
20C	To evaluate augmented spark igniter ignition delay with maximum fuel pump inlet pressure and minimum oxidizer pump inlet pressure.	Ignition detection delay time was 0.235 sec after engine start. The peak gas generator temperature was 990°F, lowest to date at AEDC. Fuel pump stall margin was 750 gpm in the high-level region.
20D	To evaluate the engine start transient at nominal S-II starting energy and the minimum sequence ramp limit for the main oxidizer valve.	Thrust chamber ignition occurred at t_0 + 0.993 sec with 143 msec VSC and the peak gas generator temperature 1630°F. Main-stage operation was achieved at t_0 + 2.058 sec. Fuel pump stall margin was 875 gpm during VSC period, 625 gpm minimum in the high-level region.
20E	Partial transition test to evaluate fuel pump low-level stall margin at 21.5 psia inlet pressure.	Fuel pump stall margin was approximately 1900 gpm at the end of start tank discharge. No apparent tendency for either cavitation or stall with an NPSH of 115 ft at engine start.

The presentation of test results in the remainder of this section consists of a discussion of each engine firing with pertinent data comparisons. The data presented are primarily those recorded on the digital data acquisition system, except as noted.

4.2 TEST RESULTS

4.2.1 Firing J4-1801-20A

The programmed 32.5-sec engine firing was successfully accomplished. Engine start and shutdown transients are presented in Fig. 9. Fuel lead time was 1.009 sec.

The pressure altitude at engine start was 104,000 ft. Test cell pressure and engine combustion chamber pressure during the firing are presented in Fig. 10. A mixture ratio shift from 5.0 to 5.5 was accomplished at t_0 + 12.6 sec by propellant utilization valve excursion from null to the closed position. This produced the indicated 80-psi rise in chamber pressure and an associated thrust increase to the desired nominal operating level of 225,000 lb.

Thermal conditioning of engine components prior to the firing is shown in Fig. 11. The cold crossover duct condition (-94°F average temperature, Fig. 11b) combined with the start tank conditions indicated in Fig. 8c to provide a minimum expected starting energy condition for an S-II start. Oxidizer and fuel pump inlet conditions were targeted for reduced NPSH (outside the engine manufacturer's safe start envelopes) as shown in Figs. 8a and b, respectively.

Thrust chamber ignition (chamber attains 100 psia) occurred at t_0 + 1.028 sec with 32 msec of VSC during oxidizer dome prime. Mainstage operation (chamber pressure attains 550 psia) was achieved at t_0 + 2.208 sec. Gas generator peak temperature at oxidizer dome prime was 1230°F.

The main oxidizer valve began second-stage ramping movement at t_0 + 0.954 sec, 74 msec before oxidizer dome prime, an unusually short dwell time at the first-stage position. Total ramp time from the first-stage position to full open was 1725 msec. The valve moved very quickly in the early portion of the ramping period, reaching 22 deg open by the end of the 32-msec VSC period. The very fast ramping movement is attributed to the 1355-msec dry-sequence orificing time and reduced hydraulic torque afforded by the minimum expected S-II starting energy condition.

Because the main oxidizer valve left the first-stage position early, the gas generator oxidizer supply pressure rate of increase was reduced significantly because of reduced resistance to oxidizer flow presented by the partially open valve. The result was reduced gas generator power buildup in proportion to the back pressure being developed

on the fuel pump as thrust chamber pressure increased. The cold thrust chamber pre-chill, -223°F at the throat and -250°F average tube temperature at engine start (decreased thrust chamber resistance to fuel flow), allowed less fuel tapoff flow to the gas generator and, consequently, delayed gas generator power development at the beginning of bootstrap operation. The combined result of the fast main oxidizer valve and cold thrust chamber pre-chill was conversion of some of the fuel pump energy to head instead of flow during and following oxidizer dome prime; the fuel pump stall margin was reduced accordingly.

Figure 12 shows the performance of the fuel pump during the start transient. Fuel pump discharge flow exhibited a slight decrease after oxidizer dome prime until the fuel pump reached 14, 500 rpm. At the 14, 500 rpm point, the pump began to recover from the potential stall condition reaching a minimum high-level stall margin of 450 gpm at 18, 600 rpm.

Evaluation of the effect of heavier oxidizer turbine wheels on the start transient for this firing can be made by comparing start transient characteristics with a previous firing, J4-1801-13A (Ref. 5), which was conducted with an oxidizer turbopump having lighter turbine wheels and the objective to evaluate conditions for a potential high-level fuel pump stall. In making this data comparison, effects of two other engine component differences must be recognized:

(1) A different main oxidizer valve was installed for Test J4-1801-13 orificed for a dry-sequence ramp time of 1385 msec.

(2) A different oxidizer turbine bypass valve was installed for Test J4-1801-13 having a 17-percent smaller (area) bypass nozzle.

Starting conditions for the two firings were comparable except for crossover duct temperature, and engine start transient characteristics compared closely as shown below and in Fig. 14:

Firing Number J4-1801-	20A	13A
Thrust Chamber Ignition, sec (Ref. t_0)	1.026	1.043
Gas Generator Peak Temperature, °F	1230	1455
Vibration Safety Counts, msec	32	33
Main Oxidizer Valve		
Initial Second-Stage Movement, sec (Ref. t_0)	0.954	0.982
[1]Torque at Initiation of Second-Stage Ramp, in. -lb_f		
Actuator	197	174
Hydraulic	108	101
Net Opening	89	73
Second-Stage Ramp Time, msec	1725	1875
Fuel Pump Stall Margin, gpm		
At Oxidizer Dome Prime	900	1150
At Approximately 18,600 rpm	450	550
Thrust Chamber Pressure Buildup Time to 550 psia, sec (Ref. t_0)	2.208	2.245

[1]See Appendix IV for methods of calculations.

Thrust chamber temperatures at engine start for these two firings differed by only 13°F average tube temperature, firing 13A being colder. Thus, fuel pump discharge and gas generator fuel injector pressures were essentially the same until gas generator ignition, leaving any difference in oxidizer pump discharge and gas generator oxidizer injector pressures to be reflected in the gas generator ignition characteristics (Fig. 13). Figure 13b shows that gas generator chamber pressure was practically identical (approximately 90 psia) for the two firings until oxidizer dome prime. As the oxidizer dome primed, fuel pump discharge pressure (Fig. 13a) peaked to a higher level during firing 20A reducing the gas generator peak temperature by 225°F lower than firing 13A. The earlier oxidizer dome prime on firing 20A, which resulted from an earlier main oxidizer valve second-stage movement, therefore accounts for the lower peak temperature during firing 20A. The difference in second-stage ramp characteristics accounts for the closer approach to fuel pump high-level stall during firing 20A.

The heavier-turbine-wheel oxidizer pump for firing 20A spun up to a lower peak speed than the lighter-turbine-wheel pump for firing 13A during start tank discharge as indicated in Fig. 13a by approximately 3- or 4-psi difference in peak nominal discharge pressure levels. Data acquisition anomolies prevented the recovery of oxidizer pump speed data (NOP-1P) recorded during firing 20A; however, the peak spin speed for firing 20A is estimated to have been approximately 3135 rpm. The estimate was derived by straight-line interpolation of firing 20A data between peak spin-speed data from firings J4-1801-17A and 18A

(Ref. 2), which were conducted with the same heavier-turbine-wheel oxidizer pump, and by utilizing the start tank/crossover duct temperature differential relationship developed in Ref. 6. Start tank pressures for firings 20A, 18A, 17A, and 13A were nominally 1250 psia. The temperature differentials (using an average of TFTD-2, TFTD-3, and TFTD-8 for crossover duct temperature) and peak spin speeds[2] during start tank discharge for these four firings (including 13A) were:

Firing No.	ΔT, °F	Peak Spin Speed, rpm
17A	43	3123
18A	63	3153
20A	51	3135 (est.)
13A	64	3167

The effect of heavier turbine wheels can be seen between firings 13A and 18A as having reduced the peak spin speed by 14 rpm, assuming the starting energy to have been essentially identical for firings 13A and 18A. Thus, the difference in peak spin speeds between firings 20A and 13A is estimated to have been approximately 14 rpm attributable to the heavier turbine wheels and 18 rpm attributable to the starting energy difference.

The use of only one pair of tests to attempt precise evaluation of the heavier turbine wheel effect on peak spin speed during start tank discharge is insufficient. A comparison of peak oxidizer pump spin-speed data between firings 13A, 14A, 15A, and 07A, all of which had the minimum start tank energy condition, reveals that the heavier turbine wheels reduced an oxidizer pump peak spin speed of approximately 3100 to 3200 rpm by a nominal value of 40 rpm (in the order of 1.3 percent).

Gas generator bootstrap performance for these two firings (before oxidizer dome prime, Fig. 13b) was essentially equal. The fact that hydraulic torque acting on the main oxidizer valve was practically identical before second-stage ramp indicates that the oxidizer pump speeds decayed to the same minimum level for the two firings and that the heavier oxidizer turbine wheels had no appreciable effect on main oxidizer valve movement or on gas generator peak temperature. The differences in gas generator temperature were the direct result of the differences in main oxidizer valve second-stage opening characteristics entirely attributable to actuator torque buildup rate (second-stage closing control port orificing) and valve friction differences.

Oxidizer pump discharge pressures differed significantly in buildup rate after oxidizer dome prime during acceleration to main-stage

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[2] Data are from FM recording system.

operation, while fuel pump discharge, thrust chamber, and gas generator chamber pressures differed only slightly. Oxidizer pump acceleration rate to steady-state (main-stage) operation is a function of the energy supplied to the turbine by the gas generator and a function of the pump/turbine mass moment of inertia. For the same energy input to the turbines, the heavier-turbine-wheel pump should be expected to accelerate less rapidly. However, in the subject test series for Saturn flights AS 502 and AS 503 S-II investigation, no test comparison is available having the same energy input because the oxidizer turbine bypass nozzle was resized when the turbopump was replaced (Ref. 2). Firing 13A provides the best overall comparison available for firing 20A because of the similar test conditions at engine start and the fast main oxidizer valve sequencing.

Oxidizer pump acceleration rate is estimated for firing 13A (Fig. 13c) to have been approximately six times as great during start tank discharge as during high-level spinup to main-stage operation. Thus, the effect of increased turbine inertia which lowered the firing 20A peak spin speed during start tank discharge by approximately 1.3 percent would be expected to lower the high-level spin speed during acceleration to the steady-state level by no more than about 0.2 percent (1.3/6). This percentage of the firing 13A speed at t_0 + 3.0 sec in approximately 15 rpm (or in the order of 2-psi difference in pump discharge pressure). The higher inertia of the heavier turbine wheels accounts for approximately 2 psi of the 60-psi difference at this time between firings 20A and 13A, and the reduced energy supplied to the oxidizer turbine during firing 20A, because of turbine bypass nozzle sizing, accounts for approximately 58 psi of the difference. Thus, heavier oxidizer turbine wheels had no significant effect on the high-level buildup transients of these two firings.

4.2.2 Firing J4-1801-20B

The programmed 7.5-sec engine firing was successfully accomplished. Engine start and shutdown transients[3] are presented in Fig. 14. Engine valve operating times were consistent and normal (Table VI).

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[3]Oxidizer pump speed data (NOP-1P) are from the FM recording system; the data were not recovered on the Digital Data Acquisition System for any of the Test 20 firings. All oxidizer pump speed comparisons with previous firings in this report are made using FM system data only.

The pressure altitude at engine start was 110,000 ft. Test cell pressure and engine combustion chamber pressure are presented in Fig. 15. Thermal conditioning of selected engine components before the firing is shown in Fig. 16.

Ignition was detected in the augmented spark igniter 122 msec after engine start. Fuel lead time was 1.002 sec. Thrust chamber ignition occurred at t_0 + 1.033 sec with 134 msec of vibration safety counts during oxidizer dome prime. The main oxidizer valve began to ramp from the first-stage position at t_0 + 0.978 sec, 55 msec before oxidizer dome prime. The second-stage ramp time was 1691 msec, the fastest recorded to date in the AEDC test program.

Initial gas generator operation during the bootstrap operation period, before oxidizer dome prime, exhibited unusually low power development; gas generator chamber pressure decayed to a minimum of approximately 80 psia at t_0 + 0.9 sec. The peak gas generator temperature was 1400°F at oxidizer dome prime.

The fuel pump start transient characteristics were very similar to those observed during firing 20A. The fast main oxidizer valve second-stage movement resulted in a minimum stall margin of 475 gpm at approximately 18,600 rpm, t_0 + 1.85 sec, as shown in Fig. 17. The main oxidizer valve moved from 17 to 27 deg during the oxidizer dome prime VSC period. The fuel flow rate was reduced by approximately 400 gpm during oxidizer dome prime. Fuel flow rate levels were identical for firings 20A and 20B from t_0 + 1.4 sec to steady-state operation.

The effect of heavier oxidizer turbine wheels on the engine start transient, for start tank conditions of 1200-psia pressure and -200°F temperature, is shown to be insignificant when compared to the effects of thrust chamber pre-chill differences between firings 20B and 16A (Ref. 7). Firing 16A was conducted using the lighter-turbine-wheel oxidizer turbopump and with target conditions at engine start similar to those of firing 20B, with the exception of crossover duct temperature. Both firings were targeted for a thrust chamber throat temperature of -250 ± 25°F. Although target conditions were satisfied, the average thrust chamber tube temperatures were -287°F for firing 20B and -215°F for firing 16A, a difference of 72°F. Other engine configuration changes having significant bearing on this data comparison were the same that were listed in 4.2.1 above between firings 20A and 13A with one exception, the main oxidizer valve was orificed for a dry-sequence ramp time of 1420 msec for test J4-1801-16.

Engine start transient comparisons for the two firings are shown in Fig. 18 and below.

Firing No. J4-1801-	20B	16A
Thrust Chamber Ignition, sec (Ref. t_0)	1.033	1.028
Gas Generator Peak Temperature, °F	1400	1389
Vibration Safety Counts, msec	134	88
Main Oxidizer Valve		
Initial Second-Stage Movement, sec (Ref. t_0)	0.978	1.026
Torque at Initiation of Second-Stage Ramp, in.-lb_f		
Actuator	258	276
Hydraulic	107	104
Net Opening	151	172
Second-Stage Ramp Time, msec	1691	1943
Fuel Pump Stall Margin, gpm		
At Oxidizer Dome Prime	850	1050
At Approximately 18,600 rpm	400	750
Thrust Chamber Pressure Buildup Time to 550 psia, sec (Ref. t_0)	2.241	2.081

Reference 7 reports that the main oxidizer valve second-stage initial movement during firing 16A was inconsistent with other S-II low-energy starts to date in that the main oxidizer valve did not begin to ramp before oxidizer dome prime and that this initial movement (firing 16A) was coincident with the beginning of the 88-msec VSC period. Hydraulic torque was unusually high for a low-energy start before oxidizer dome prime during firing 16A, 120-in.-lb_f at the corresponding time that the valve began to ramp during firing 20B as compared to 107 in.-lb_f for firing 20B. Oxidizer pump discharge pressure was approximately 196 psia as the oxidizer dome primed. Hydraulic torque decreased to 104 in.-lb_f as thrust chamber pressure increased to 61 psia, and the main oxidizer valve began to ramp. The higher hydraulic torque during firing 20B resulted from an immediate rise in gas generator chamber pressure after ignition to approximately 110 psia in the bootstrap period before oxidizer dome prime. The higher gas generator output for firing 16A (see shaded area, Fig. 18b) was the direct result of higher thrust chamber resistance to fuel flow (see shaded area, fuel pump discharge pressures, afforded by the warmer thrust chamber pre-chill, Fig. 18a). The result of the improved gas generator bootstrap performance (with regard to main oxidizer valve opening characteristics) was less decay in oxidizer pump spin speed and discharge pressure before oxidizer dome prime and, thus, higher hydraulic torque acting on the main oxidizer valve gate at the first-stage position.

After oxidizer dome prime, both turbopumps accelerated to main-stage steady-state levels much faster during firing 16A than during firing 20B because of the faster gas generator chamber pressure build-up rate afforded by the better initial gas generator operation and slower main oxidizer valve ramping during firing 16A. Comparing the large difference in oxidizer pump discharge pressures in the high-level build-up period between firings 20B and 16A (approximately 140 psi at t_0 + 2 sec, Fig. 18a) with the 60-psi maximum difference between firings 20A and 13A (Fig. 13a), the above described difference in gas generator performance appears large with respect to the effect of the 17-percent larger oxidizer turbine bypass nozzle discussed in 4.2.1 above.

The fuel and oxidizer pump discharge pressure high-level buildup transients of firings 20A and 20B were practically identical, and the 4.2.1 discussion showed the effect of heavier oxidizer turbine wheels to have been insignificant, with respect to the oxidizer turbine bypass nozzle effect, between firings 20A and 13A.

The peak oxidizer pump spin speed during start tank discharge for 16A was 3290 rpm and for firing 20B was 3211 rpm (a difference of approximately 80 rpm). Firings 16D and 19A were also conducted with nominal start tank conditions of 1200 psi and -200°F, and the heavier-turbine-wheel oxidizer pump was installed for firing 19A. Start tank/crossover duct temperature differentials and peak spin speeds for these four firings are compared as follows:

Firing No.	ΔT, °F	Peak Spin Speed, rpm	Turbine Wheels
19A	103	3175	Heavy
20B	110	3211	Heavy
16A	144	3290	Light
16D	140	3274	Light

The peak spin-speed difference between firings 20B and 16A (weighted by firing 16D) shows approximately 30 rpm attributable to turbine inertia and 50 rpm attributable to starting energy differences after extrapolating the data for heavier turbine wheels to 140°F temperature differential. However, the same comparison with firing 19A shows approximately 55 rpm difference attributable to turbine inertia and 60 rpm attributable to starting energy differences. Thus, averaging the two comparisons for these start tank conditions, the effect of heavier turbine wheels was approximately 40 rpm on the peak spin speed, the same as that for the start tank conditions of 1250 psi and -140°F tested in firing 20A.

4.2.3 Firing J4-1801-20C

The programmed 7.5-sec engine firing was successfully accomplished. Engine start and shutdown transients are presented in Fig. 19. Engine valve operating times were consistent and normal (Table VI).

The pressure altitude at engine start was 111,000 ft. Test cell pressure and engine combustion chamber pressure are presented in Fig. 20. Thermal conditioning of selected engine components before the firing is shown in Fig. 21.

Thrust chamber ignition occurred at t_0 + 0.997 sec with 80 msec of vibration safety counts. The main oxidizer valve initial second-stage movement occurred at t_0 + 0.963 sec. Gas generator ignition was immediate, and combustion was very smooth as the oxidizer poppet opened; the peak gas generator temperature was the lowest recorded to date at AEDC, 990°F. The main oxidizer valve second-stage ramp time was 1737 msec. Main-stage operation (550-psia chamber pressure) was achieved at t_0 + 2.083 sec.

Improved gas generator performance (higher gas generator exhaust flow) as bootstrap operation began and the very low, 990°F, peak temperature were afforded by the warm thrust chamber pre-chill (-170°F average chamber tube temperature). Performance of the fuel pump during the start transient is shown in Fig. 22. Reduced fuel pump high-level stall margins (450-475 gpm) for firings 20A and 20B were the result of low gas generator power and fast main oxidizer valve ramping movement. Comparison of the fuel pump head-flow and pump speed transients of firing 20C with firings 20A and 20B shows that improved gas generator transient performance, despite fast main oxidizer valve movement on firing 20C, provided increased stall margin. The minimum high-level stall margin for firing 20C was 750 gpm (at 19,100 rpm). The fuel flow at the time of minimum low-level stall margin (before oxidizer dome prime) was approximately 500 gpm greater than firing 20B although starting energy for both firings was identical.

Augmented spark igniter ignition detection delay time is shown in Fig. 23 to have a relationship with engine pump inlet pressures at engine start. The delay time for firing 20C was 235 msec from engine start with fuel pump inlet pressure set 4.6 psi higher than oxidizer pump inlet pressure. For firings 20A, 20B, 20D, and 20E, oxidizer inlet pressure was set nominally 7 psi higher than fuel pump inlet pressure, and ignition detection delay time varied from 122 msec for firing 20B to 202 msec for firing 20E.

4.2.4 Firing J4-1801-20D

The programmed 7.5-sec firing was successfully accomplished. Engine start and shutdown transients are presented in Fig. 24. Engine valve operating times were consistent and normal (Table VI).

The pressure altitude at engine start was 110,000 ft. Test cell pressure and engine combustion chamber pressure are presented in Fig. 25. Thermal conditioning of selected engine components before the firing is shown in Fig. 26.

The crossover duct temperature (-7°F average at engine start) combined with the start tank conditions shown in Fig. 8c to provide nominal starting energy conditions. Fuel lead time was 1.002 sec. Ignition was detected in the augmented spark igniter 143 msec after engine start.

Thrust chamber ignition occurred at t_0 + 0.993 sec with 143 msec of vibration safety counts during oxidizer dome prime. The main oxidizer valve began to ramp from the first-stage position at t_0 + 1.009 sec (during the VSC period). The peak gas generator temperature was 1630°F. The main oxidizer valve opening characteristics for this firing are shown in detail from oscillograph and FM system data presented in Fig. 27. Net opening torque was 145 in.-lb_f (Table VII) at the time of valve second-stage initial movement. Hydraulic torque acting on the gate was higher before oxidizer dome prime during firing 20D than during firings 20A, 20B, and 20C because of the higher starting energy; the torque was reduced from 112 to 19 in.-lb_f minimum as the oxidizer dome primed. The valve began to ramp at a time that chamber pressure was 109 psia, 21 msec after VSC began (Fig. 27a). The vibration apparently reduced the valve frictional torque, influencing the valve to begin to ramp open at an accelerated rate, evidenced by the fact that actuator torque actually decreased until VSC ceased (Fig. 27b). The valve second-stage opening time was 1830 msec. Thrust chamber pressure buildup to 550 psia required 2.058 sec (from t_0).

Transient performance of the fuel pump is shown in Fig. 28. The minimum stall margin during the 143-msec VSC period was 875 gpm (at 13,800 rpm), and the minimum high-level stall margin was 600 gpm (at 18,700 rpm). Comparing fuel pump start transient performance for firing 20D with the performance for firing 20B (Fig. 19), the dome prime stall margin during the 134-msec VSC period of firing 20B was 850 gpm, 25 gpm less than the firing 20D margin. However, the faster gas generator chamber pressure buildup during firing 20D increased the main oxidizer valve second-stage ramp time by 139 msec and increased the minimum fuel pump high-level stall margin by approximately 125 gpm greater than that of firing 20B.

4.2.5 Firing J4-1801-20E

The programmed firing of 0.875-sec duration was successfully accomplished. Fuel lead time was 1.007 sec. Engine start and shutdown transients are presented in Fig. 29. Engine valve operating times were consistent and normal (Table VI). Ignition was detected in the augmented spark igniter chamber 202 msec after engine start.

The pressure altitude at engine start was 112,000 ft. Test cell pressure and engine combustion chamber pressure are presented in Fig. 30. Thermal conditioning of selected engine components before the firing is shown in Fig. 31.

The fuel pump inlet was conditioned to a very low pressure (21.5 psia) as shown in Fig. 8b. High starting energy was afforded by the start tank conditions, shown in Fig. 8c, and the warm crossover duct temperature, 39°F average. The thrust chamber was pre-chilled to -234°F at the throat. The gas generator peak temperature was 1715°F at t_0 + 0.95 sec. Transient performance of the fuel pump is shown in Fig. 32. Fuel pump NPSH was well below the engine manufacturer's minimum model specification line (Ref. 8 and Fig. 32c) throughout the firing duration. Fuel pump low-level stall margin was 1900 gpm at the end of start tank discharge. There was no apparent increased tendency for fuel pump cavitation or degradation in fuel pump transient performance (as indicated by satisfactory engine start transient characteristics) from starting the engine with 115-ft NPSH during this firing.

4.3 ENGINE STEADY-STATE PERFORMANCE

Engine steady-state performance data are presented in Table VIII for a 1-sec data average between 29 and 30 sec after t_0 for firing 20A. These data were computed using the Rocketdyne PAST 640, modification zero, performance computer program. Engine test measurements required by the program and the program computations for the normalized data are presented in Appendix V. Propellant flow rates for actual test conditions were utilized for thrust chamber site performance computations correcting for gaseous oxygen repressurant flow rate (measured using a facility vent nozzle) and programming a facility shutoff valve to terminate the gaseous hydrogen repressurant flow early in the main-stage portion of the firing.

4.4 POST-TEST INSPECTION

Post-test inspection showed the engine to be in satisfactory condition. Visual examination of the augmented spark igniter revealed no signs of chamber erosion or excessive temperature. No engine components required replacement because of unsatisfactory condition.

SECTION V
SUMMARY OF RESULTS

The results of these five firings of the J-2 engine (S/N J-2047) conducted on December 14, 1967, in Test Cell J-4 are summarized as follows:

1. Limited data comparisons revealed that heavier oxidizer turbine wheels had an insignificant effect for low starting-energy firings 20A and 20B on the engine start transient characteristics, i. e., main oxidizer valve second-stage opening, gas generator transient temperatures, fuel pump stall margin, and thrust chamber buildup to main-stage operation.
2. The test conditions at engine start for firing 20A combined to produce a fast main oxidizer valve second-stage ramp time, 1725 msec, beginning 74 msec before oxidizer dome prime. The result was delayed gas generator power development with respect to fuel pump back pressure and the closest approach to fuel pump high-level stall observed to date at AEDC, 450-gpm stall margin.
3. The test conditions at engine start for firing 20B combined to produce the fastest main oxidizer valve second-stage ramp time recorded to date at AEDC, 1691 msec, beginning 55 msec before oxidizer dome prime. The result was approximately the same fuel pump high-level stall margin as firing 20A, 475 gpm.
4. Engine vibration during oxidizer dome prime (VSC) apparently accelerated the main oxidizer valve ramp rate during the VSC periods of firings 20A, 20B, 20C, and 20D and influenced the valve to begin the second-stage ramp 21 msec after VSC began during firing 20D. Fuel pump stall margin was reduced to approximately 850 to 875 gpm minimum during the oxidizer dome prime VSC periods of firings 20B and 20D.

5. An increased fuel pump high-level stall margin of 750 gpm was observed during firing 20C, despite fast main oxidizer valve second-stage opening time, 1737 msec, beginning 34 msec before oxidizer dome prime. Firing 20C was conducted with the same low starting-energy conditions as firing 20B but with high fuel pump NPSH and a warm thrust chamber pre-chill. The peak gas generator temperature at oxidizer dome prime was the lowest recorded to date at AEDC, 990°F.

6. The nominal starting conditions of firing 20D, despite a cold thrust chamber pre-chill, delayed the initial main oxidizer valve second-stage movement until oxidizer dome prime and produced a main oxidizer valve second-stage ramp time of 1830 msec. The fuel pump high-level stall margin was 600 gpm.

7. Augmented spark igniter ignition detection delay time for firing 20C was 235 msec from engine start with fuel pump inlet pressure set 4.6 psi higher than oxidizer pump inlet pressure. For the other firings in this test period, oxidizer inlet pressure was set nominally 7 psi higher than fuel pump inlet pressure, and ignition detection delay time varied from 122 msec for firing 20B to 202 msec for firing 20E.

8. Fuel pump NPSH was well below the engine manufacturer's minimum model specification line throughout the duration of partial transition firing 20E. Satisfactory engine start transient characteristics were obtained.

REFERENCES

1. Dubin, M., Sissenwine, N., and Wexler, H. U. S. Standard Atmosphere, 1962. December 1962.

2. Pillow, C. E. "Altitude Developmental Testing of the J-2 Rocket Engine in Propulsion Engine Test Cell (J-4) (Tests J4-1801-17 through J4-1801-19)." AEDC-TR-68-73, to be published.

3. "J-2 Rocket Engine, Technical Manual Engine Data." R-3825-1, August 1965.

4. Test Facilities Handbook (Sixth Edition). "Large Rocket Facility, Vol. 3." Arnold Engineering Development Center, November 1966.

5. Counts, H. J. "Altitude Developmental Testing of the J-2 Rocket Engine in Propulsion Engine Test Cell (J-4) (Tests J4-1801-13 through J4-1801-15)." AEDC-TR-68-16, February 1968.

6. Collier, M. R. and Dougherty, N. S., Jr. "Altitude Testing of the J-2 Rocket Engine in Propulsion Engine Test Cell (J-4) (Tests J4-1554-20 through J4-1544-26)." AEDC-TR-67-145, October 1967.

7. Kunz, C. H. "Altitude Developmental Testing of the J-2 Rocket Engine in Propulsion Engine Test Cell (J-4) (Test J4-1801-16)." AEDC-TR-68-43, April 1968.

8. "Engine Model Specification Liquid-Propellant Rocket Engine - Rocketdyne Model J-2." R-2158cS, January 1966.

APPENDIXES

I. ILLUSTRATIONS
II. TABLES
III. INSTRUMENTATION
IV. METHODS OF CALCULATIONS (MAIN OXIDIZER VALVE TORQUE)
V. METHODS OF CALCULATIONS (PERFORMANCE PROGRAM NORMALIZED DATA)

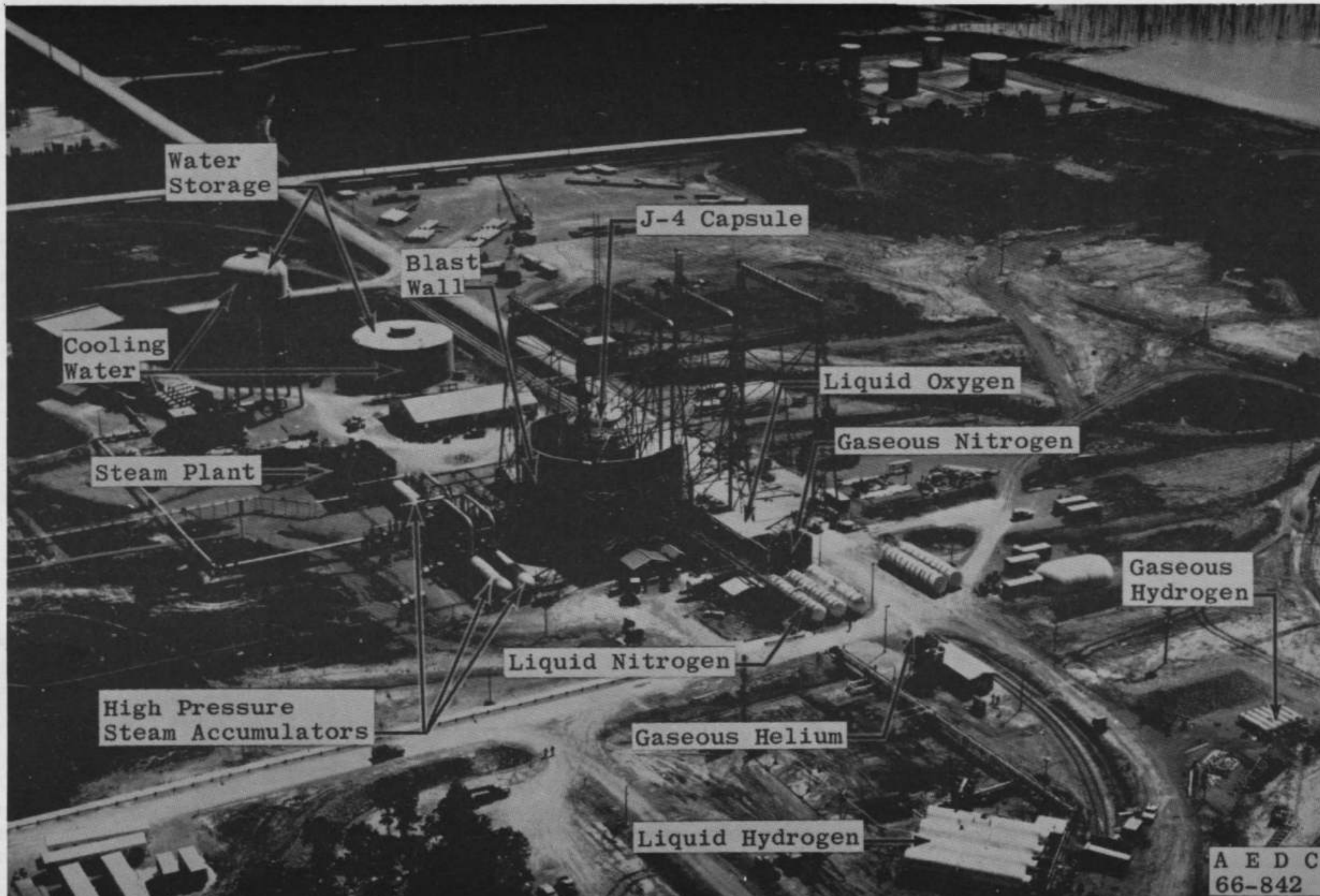


Fig. 1 Test Cell J-4 Complex

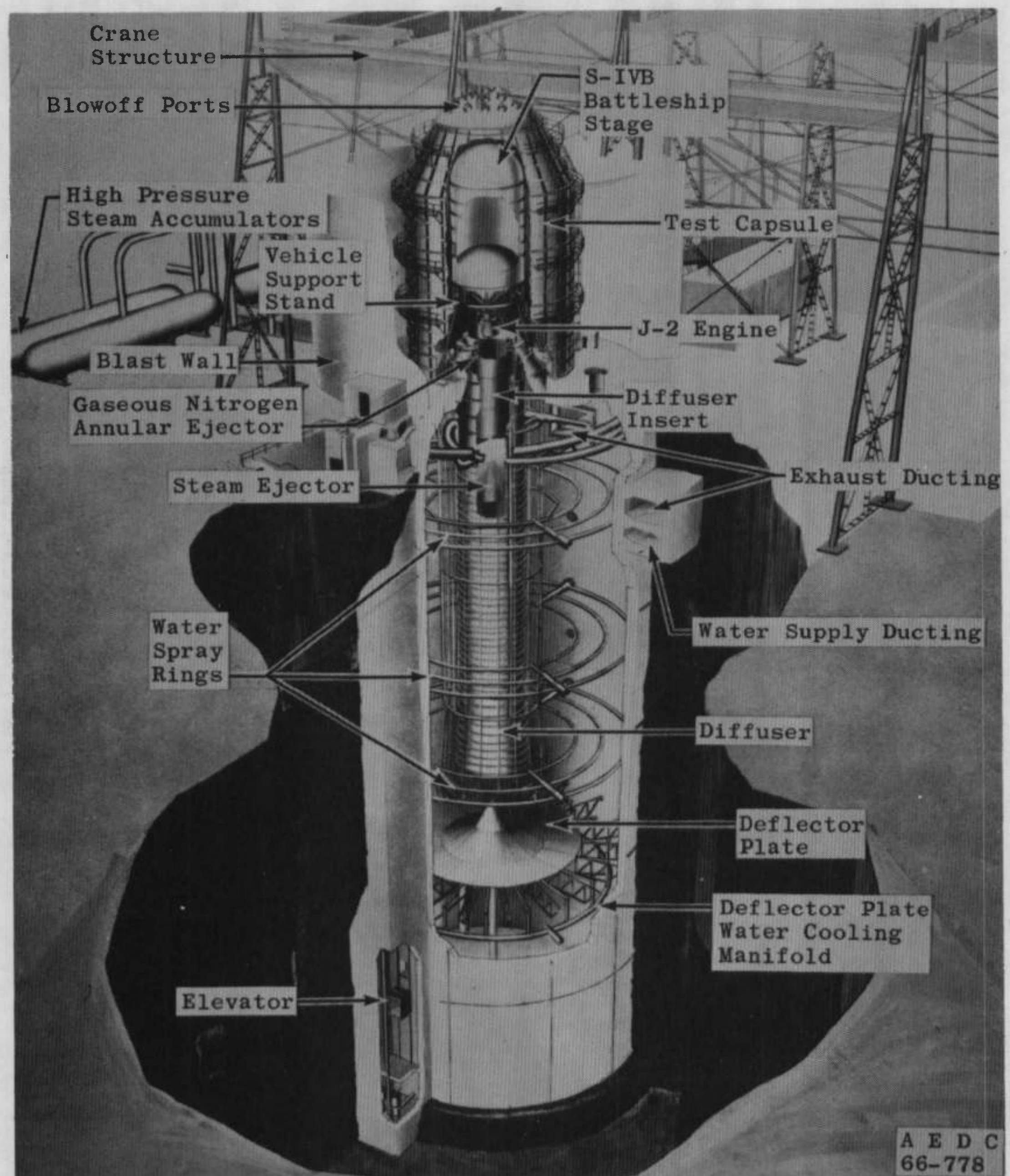


Fig. 2 Test Cell J-4, Artist's Conception

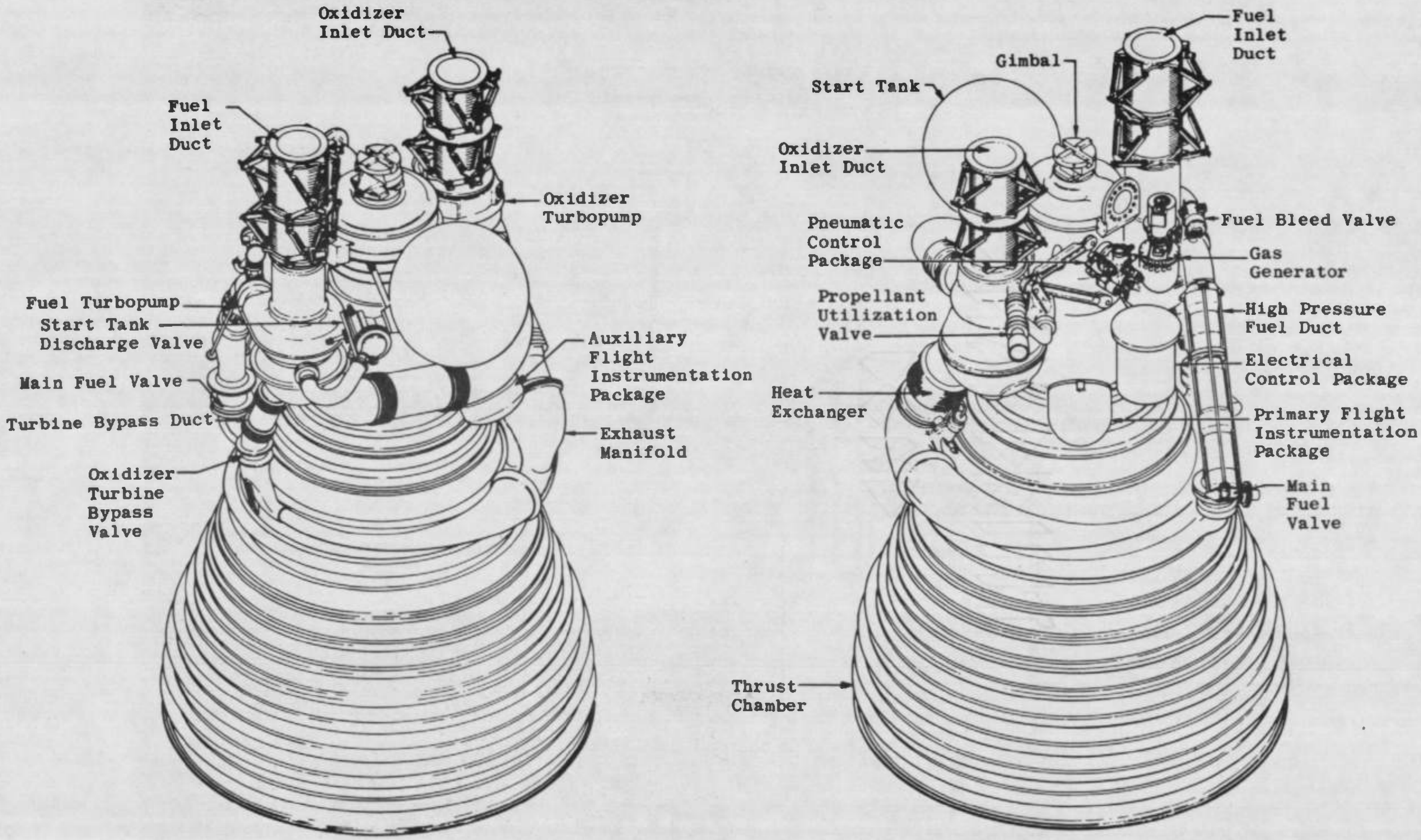


Fig. 3 Engine Details

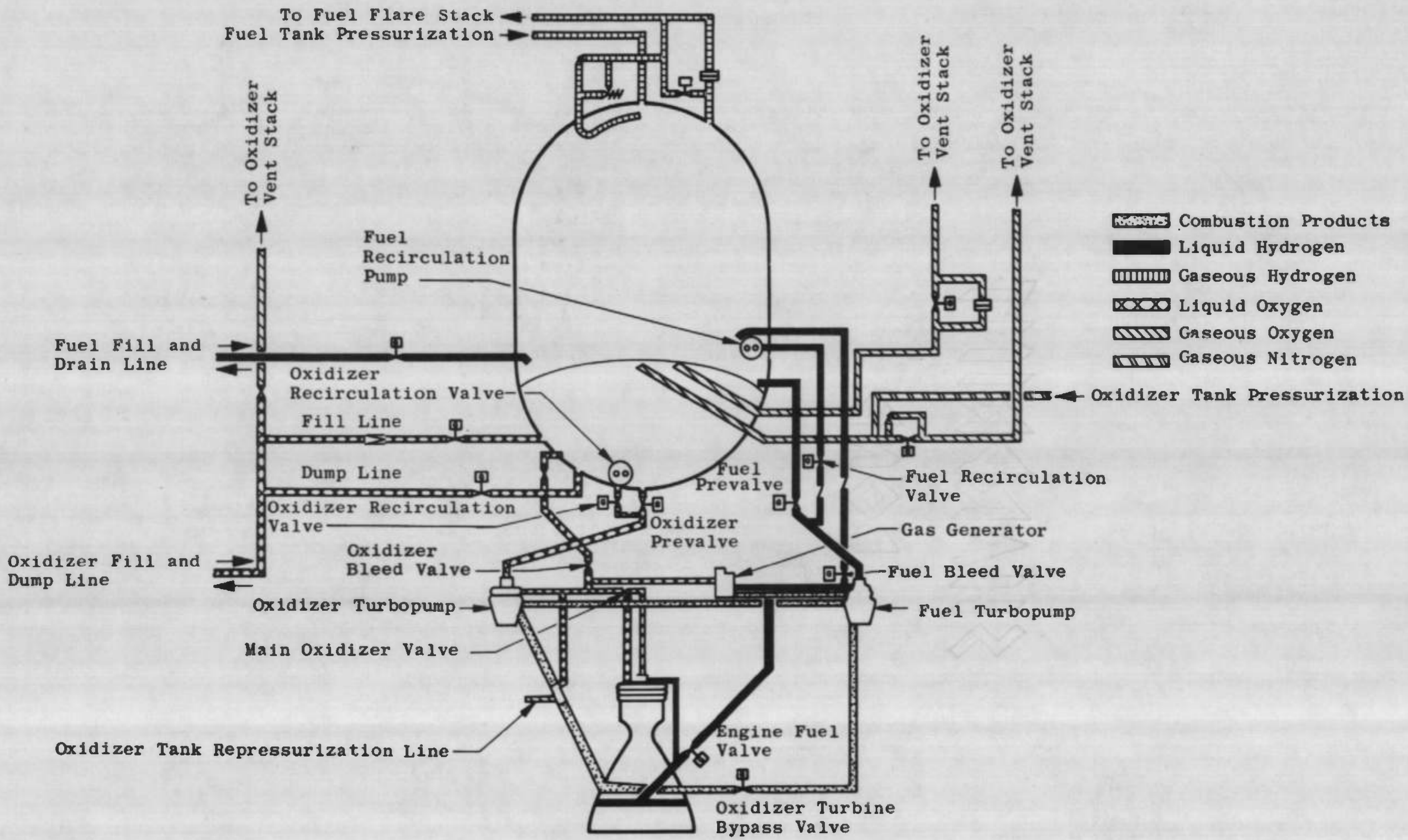


Fig. 4 S-IVB Battleship Stage/J-2 Engine Schematic

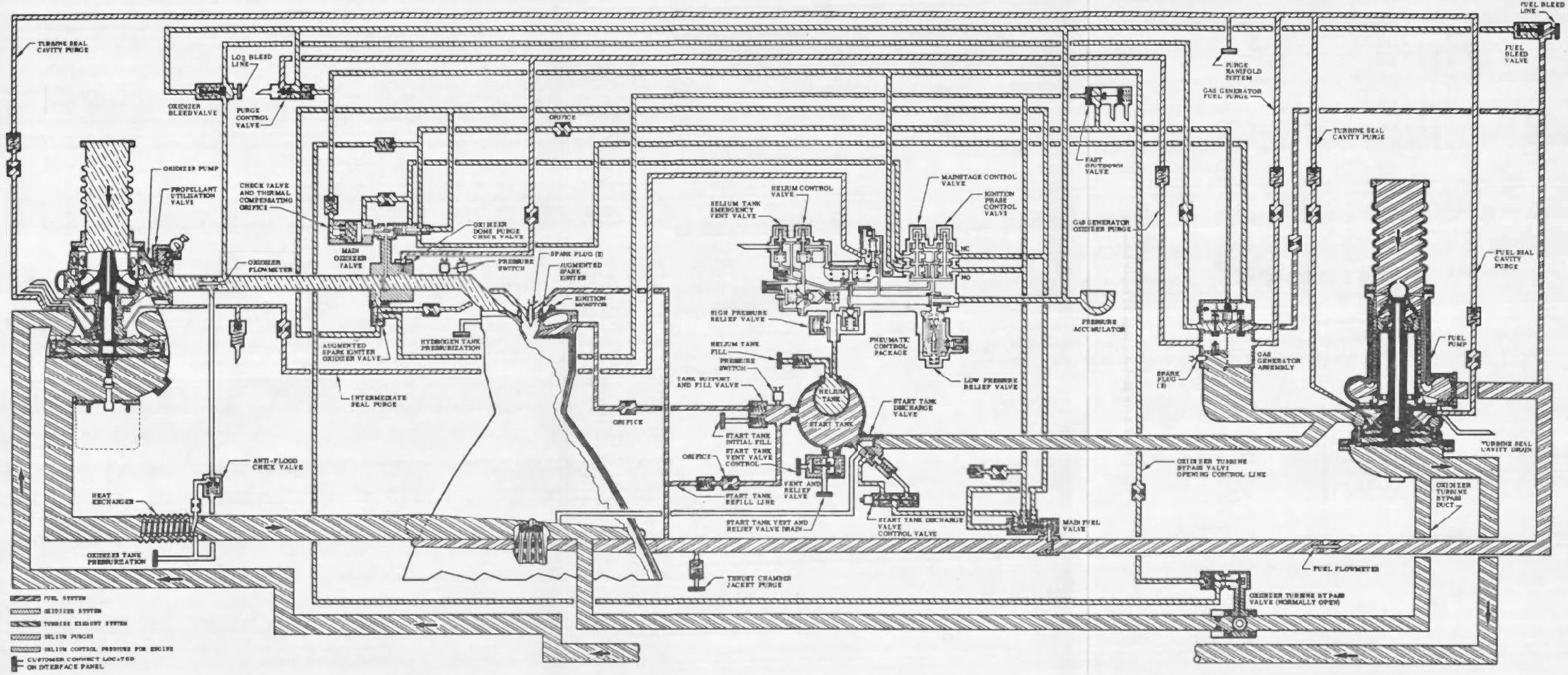


Fig. 5 Engine Schematic

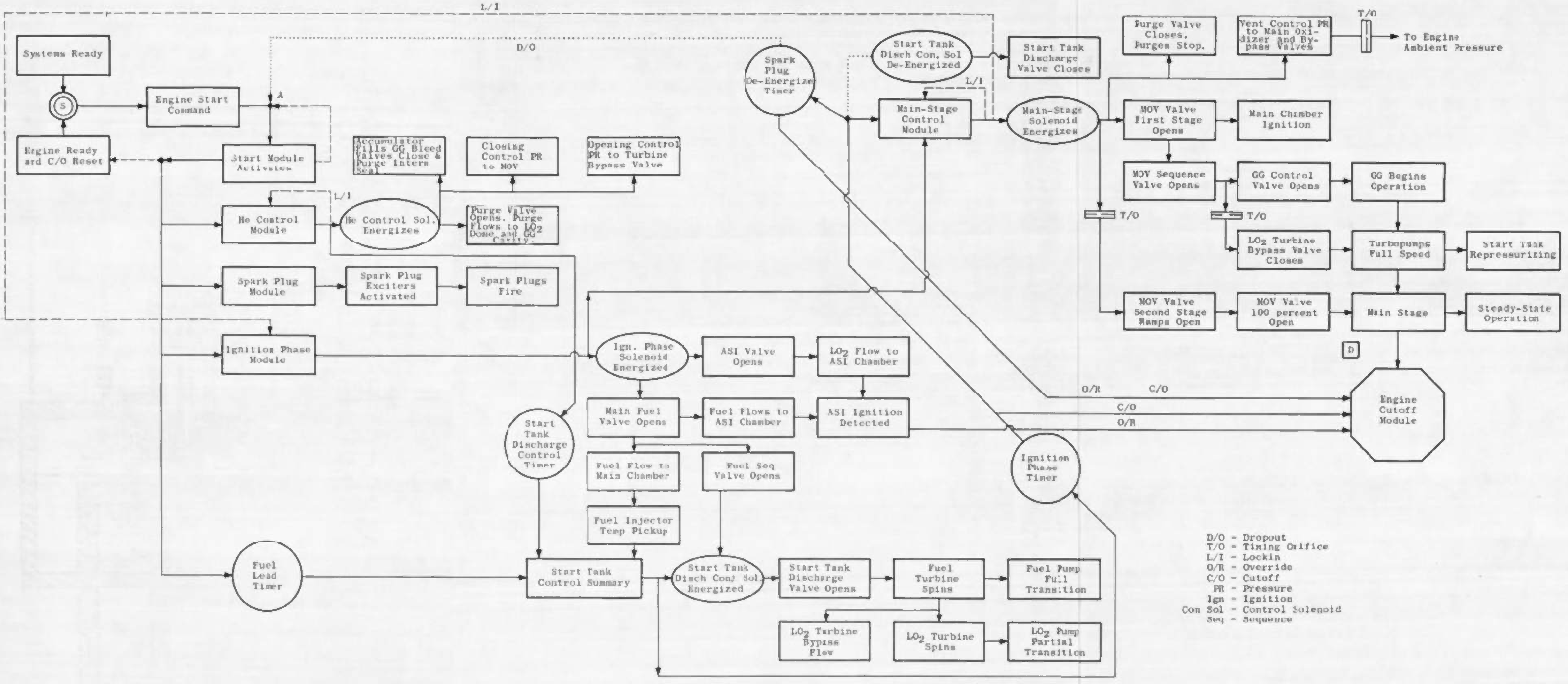
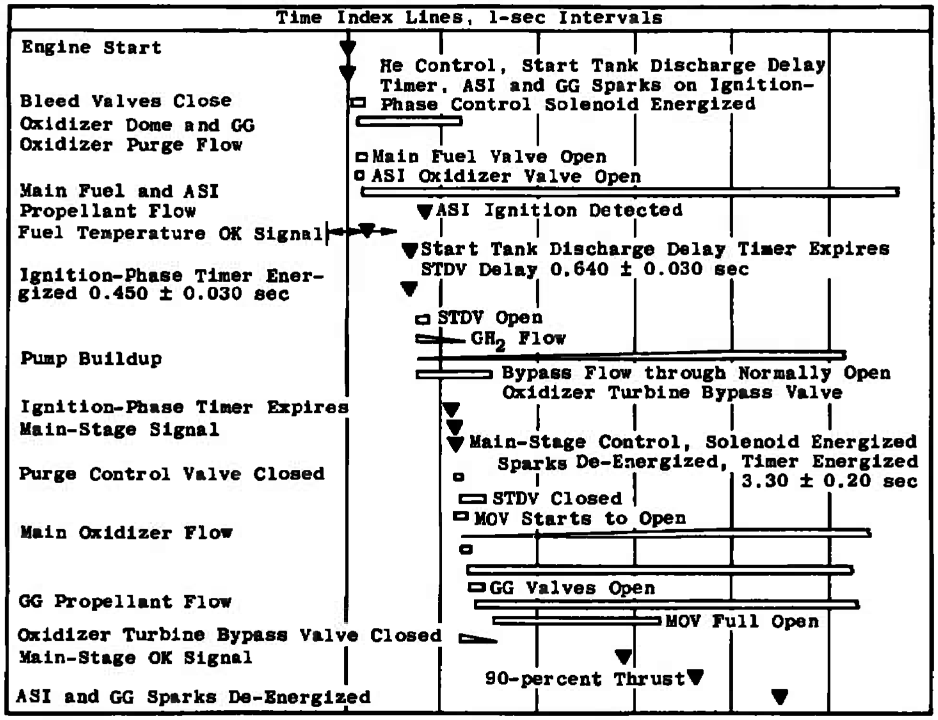
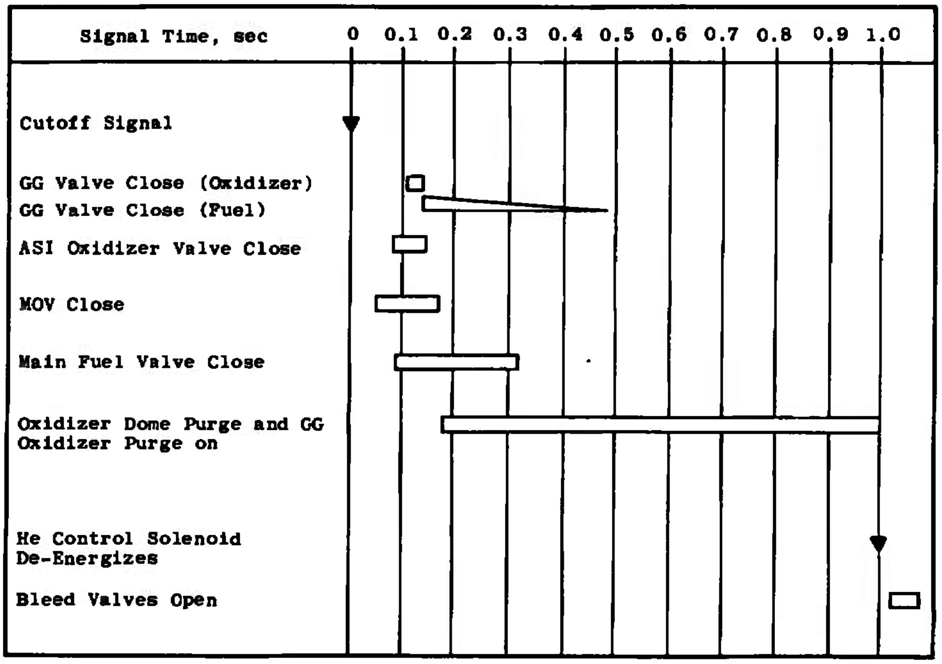


Fig. 6 Engine Start Logic Schematic

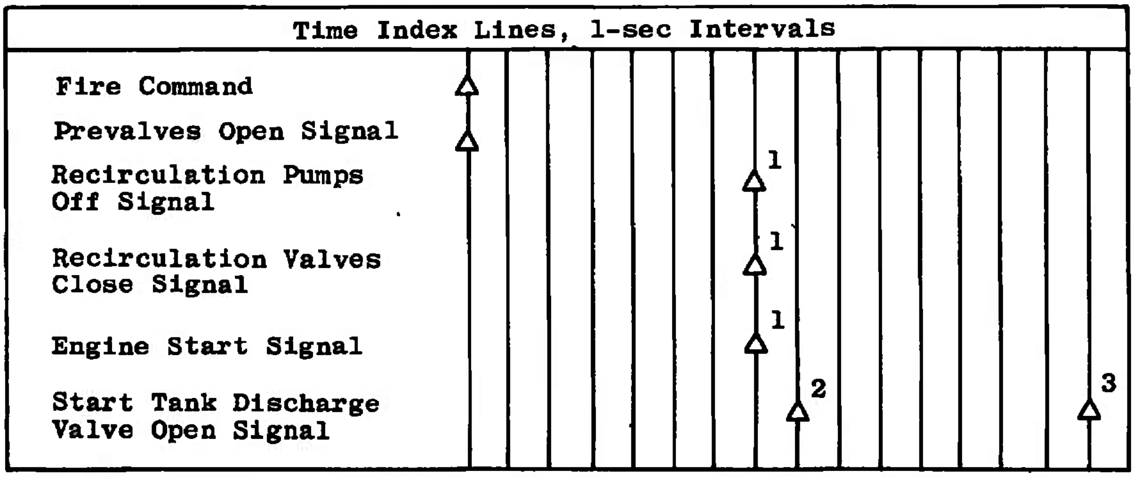


a. Start Sequence



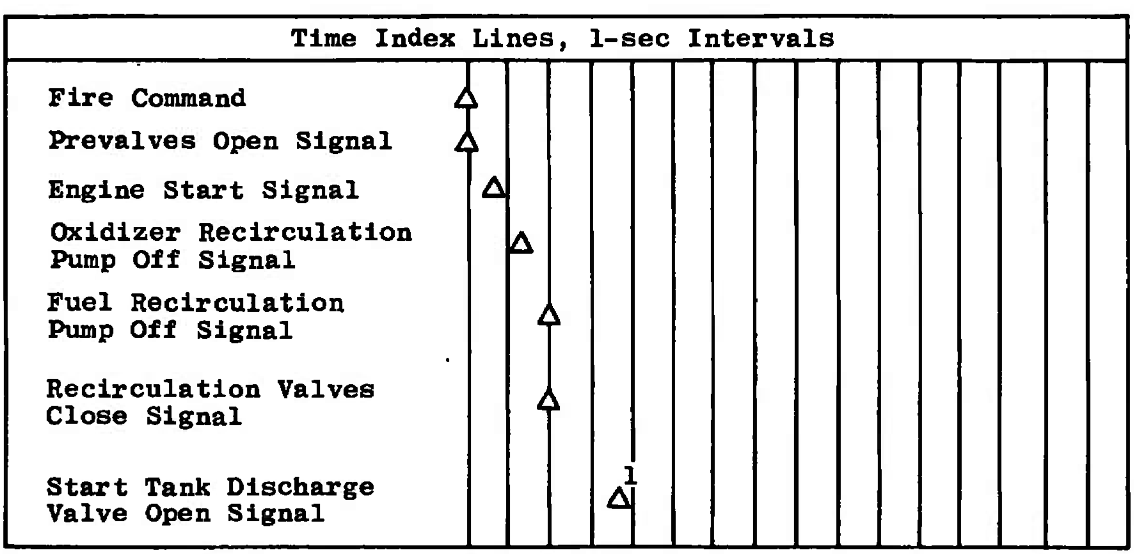
b. Shutdown Sequence

Fig. 7 Engine Start and Shutdown Sequence



[1]Nominal Occurrence Time (Function of Prevalves Opening Time)
[2]1-sec Fuel Lead (S-II/S-V and S-IVB/S-IB)
[3]8-sec Fuel Lead (S-IVB/S-V and S-IB Orbital Restart)

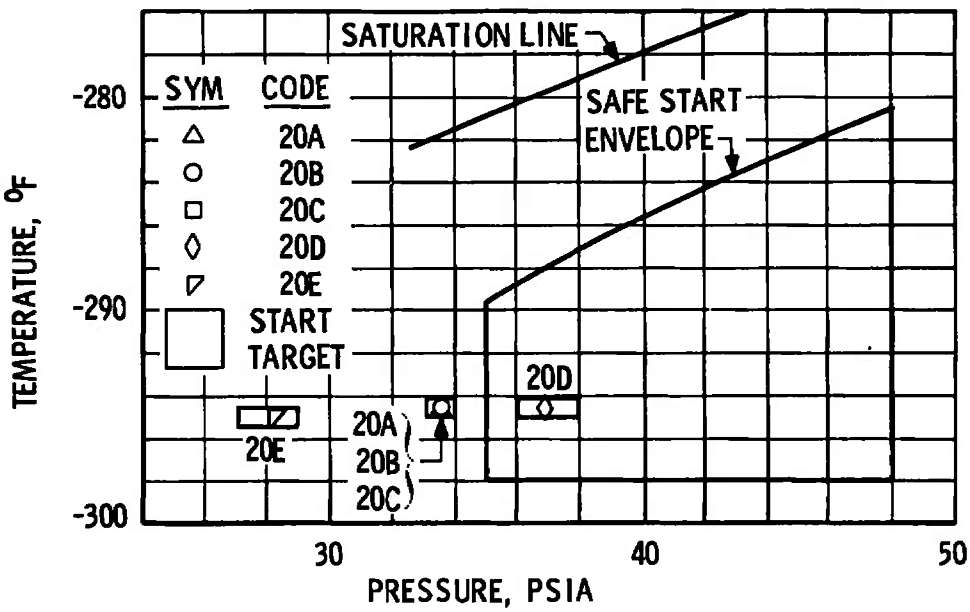
c. Normal Logic Start Sequence



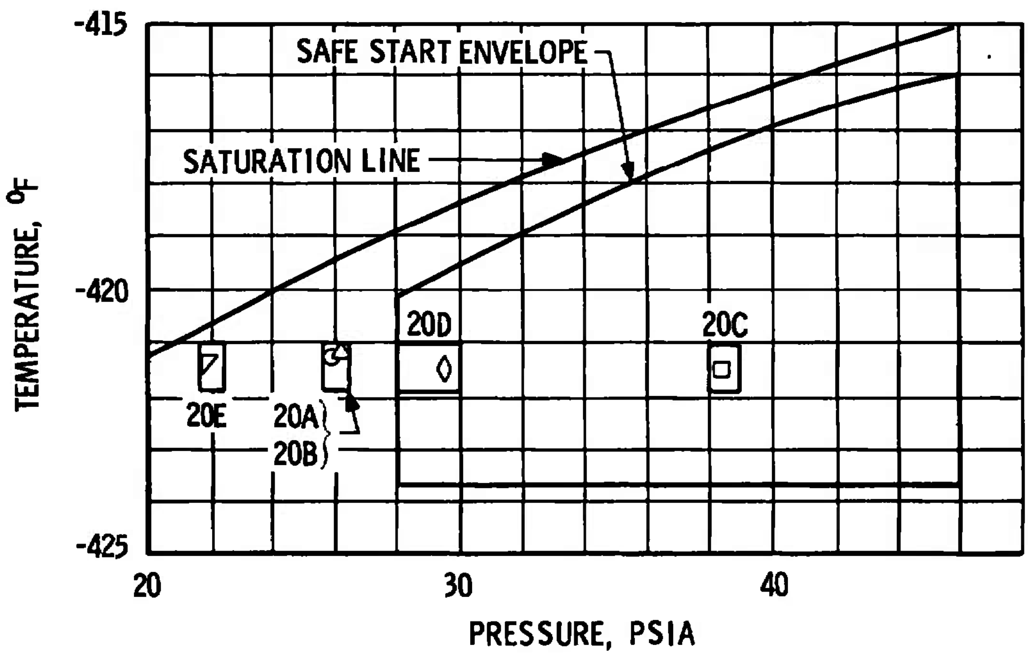
[1]3-sec Fuel Lead (S-IVB/S-V First Burn)

d. Auxiliary Logic Start Sequence

Fig. 7 Concluded

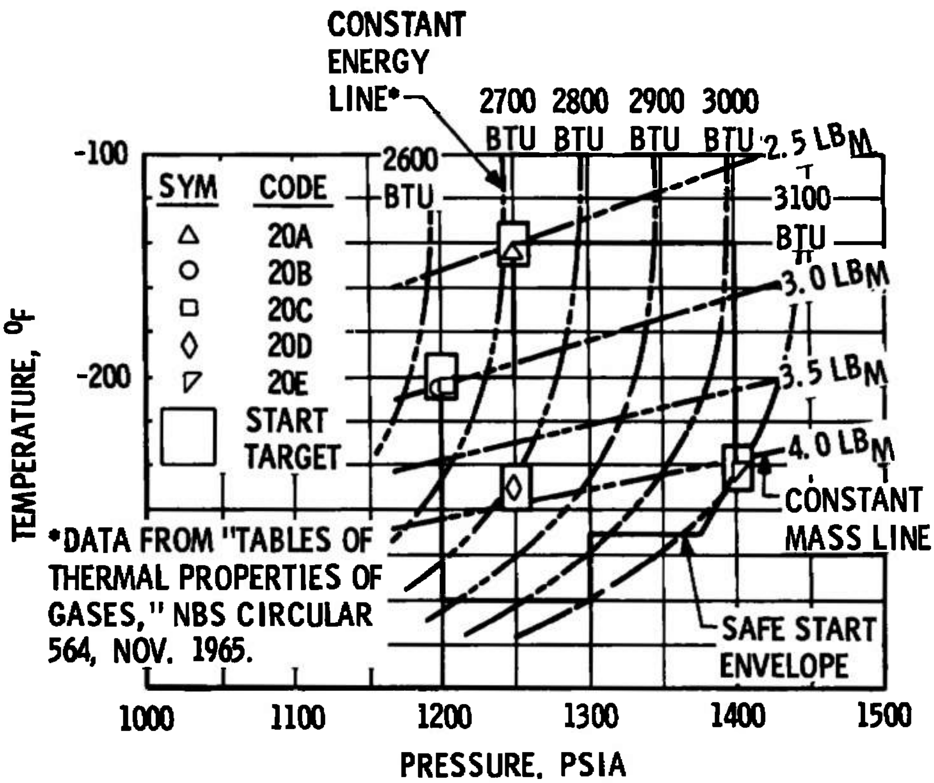


a. Oxidizer Pump Inlet

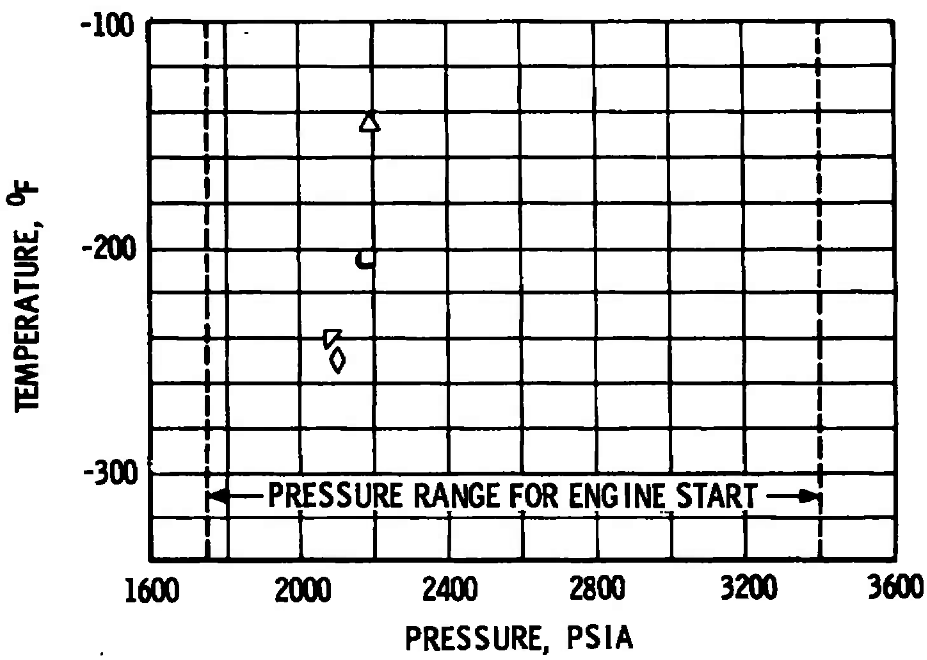


b. Fuel Pump Inlet

Fig. 8 Engine Start Conditions for Pump Inlets, Start Tank, and Helium Tank

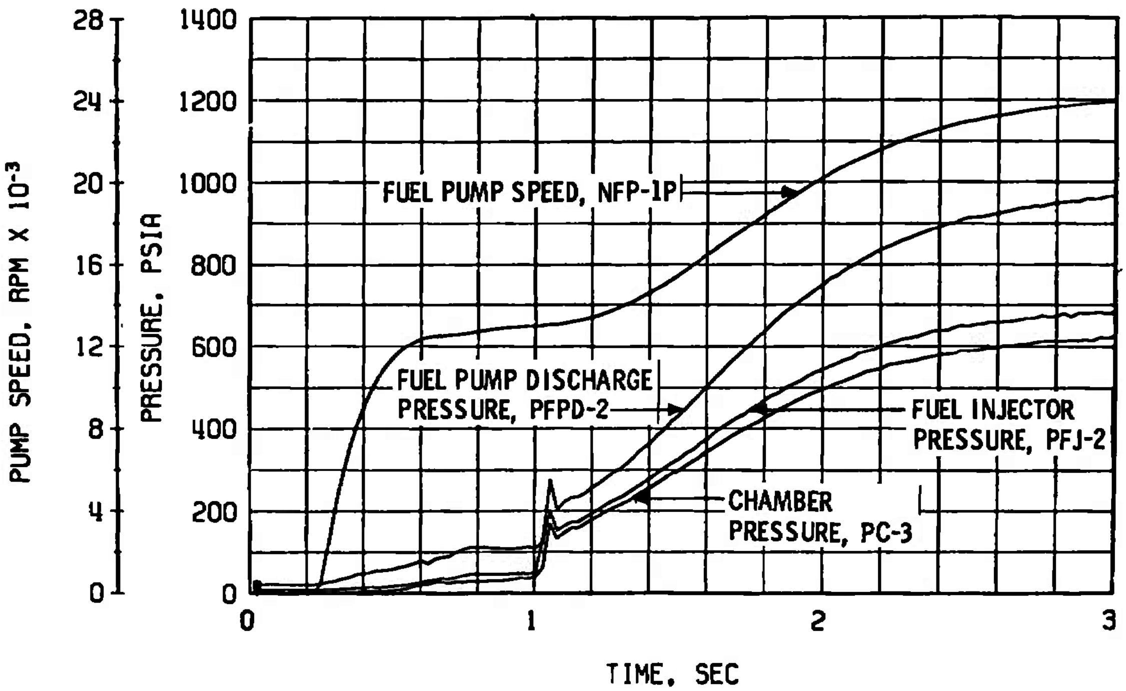


c. Start Tank

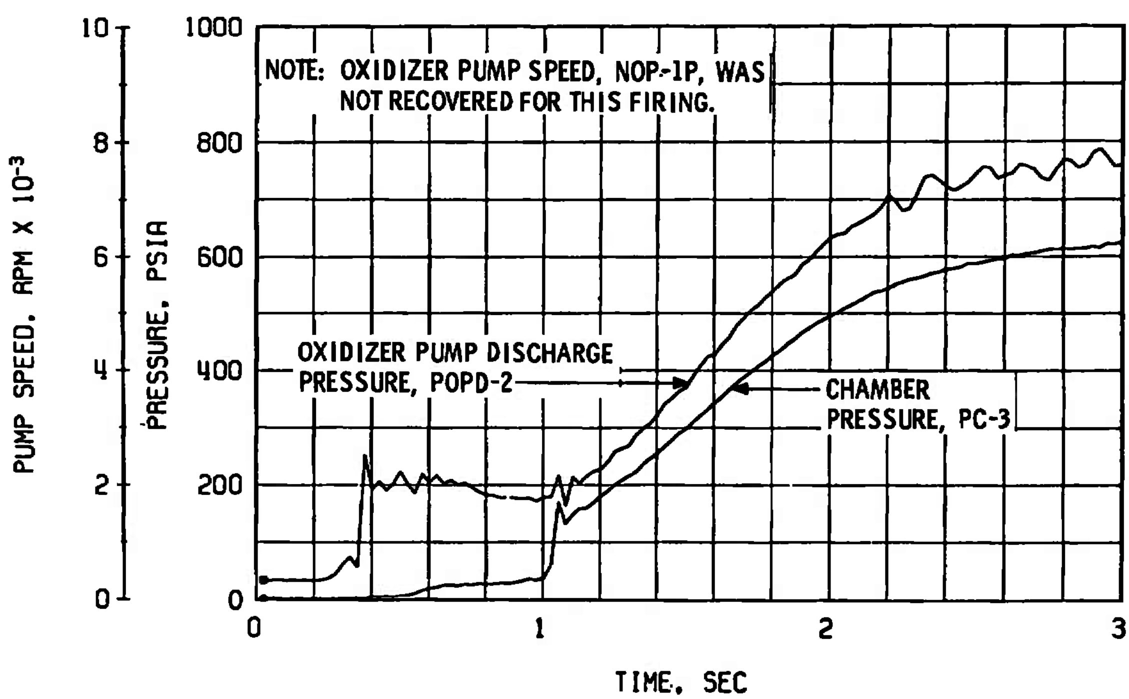


d. Helium Tank

Fig. 8 Concluded

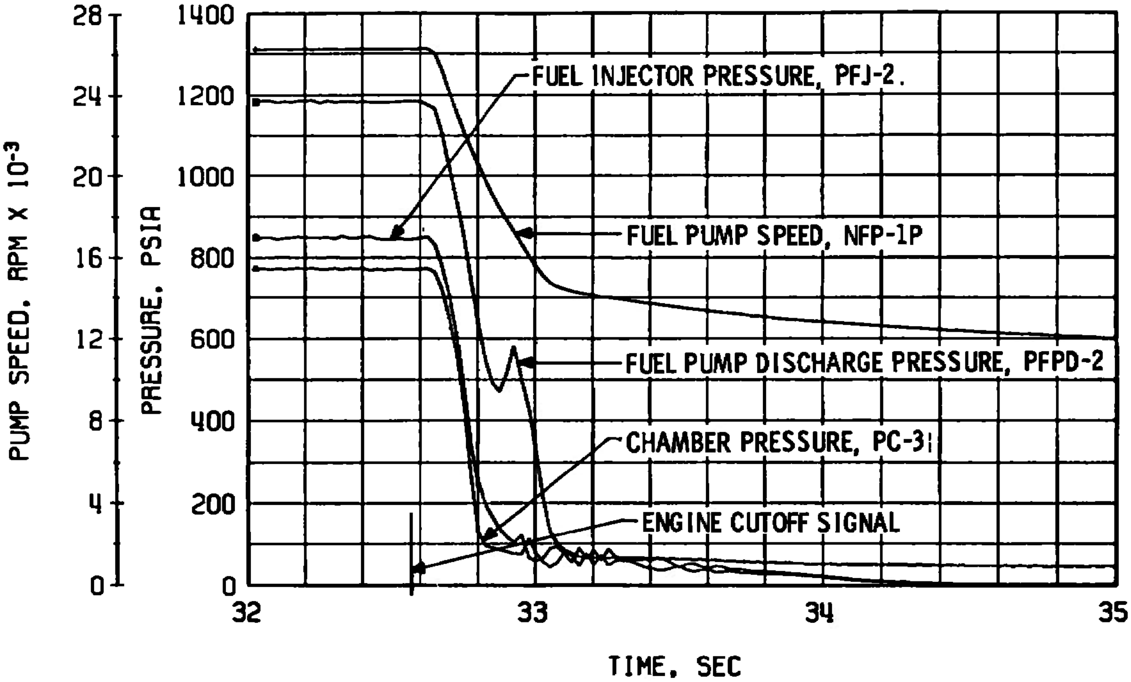


a. Thrust Chamber Fuel System, Start

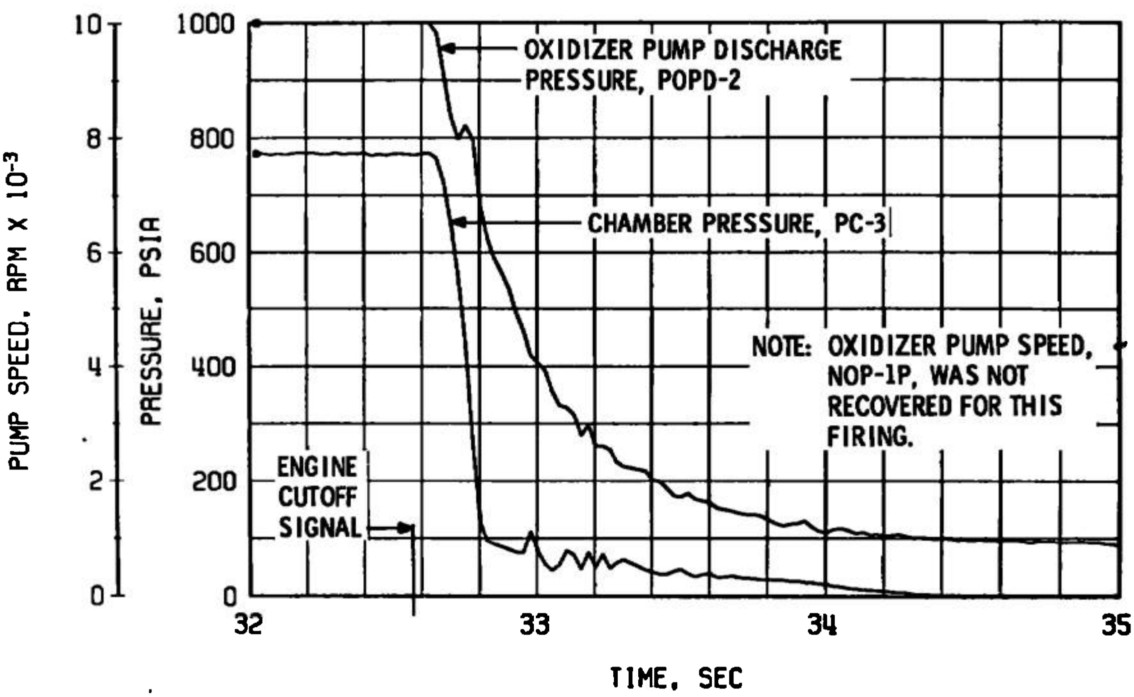


b. Thrust Chamber Oxidizer System, Start

Fig. 9 Engine Transient Operation, Firing 20A

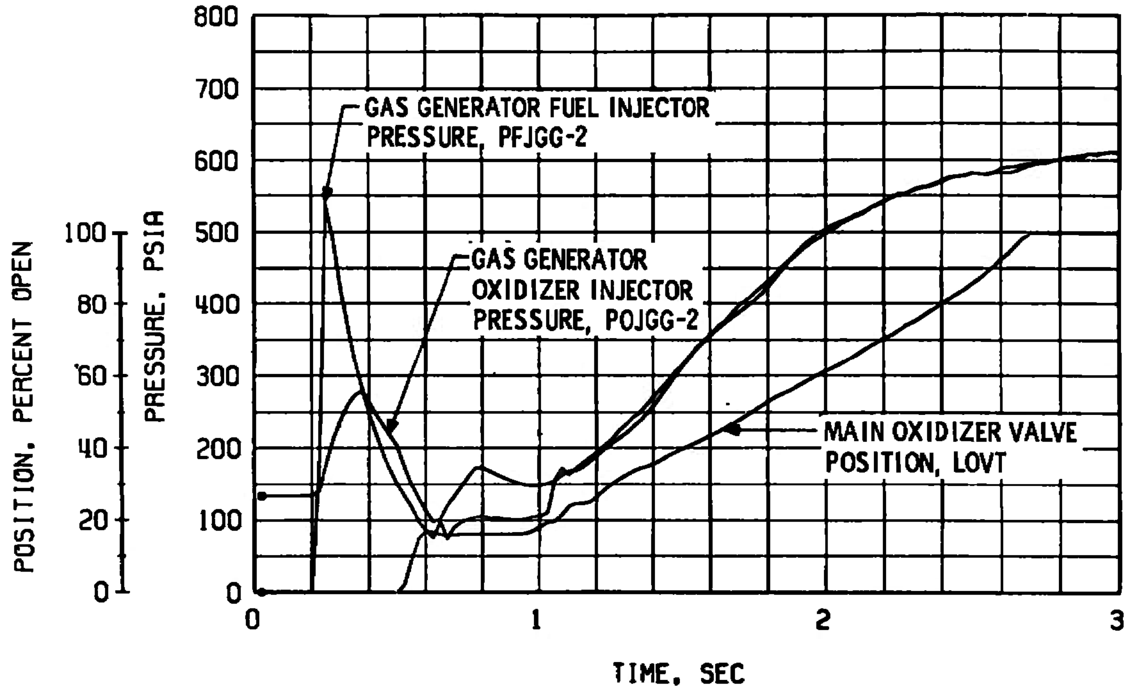


c. Thrust Chamber Fuel System, Shutdown

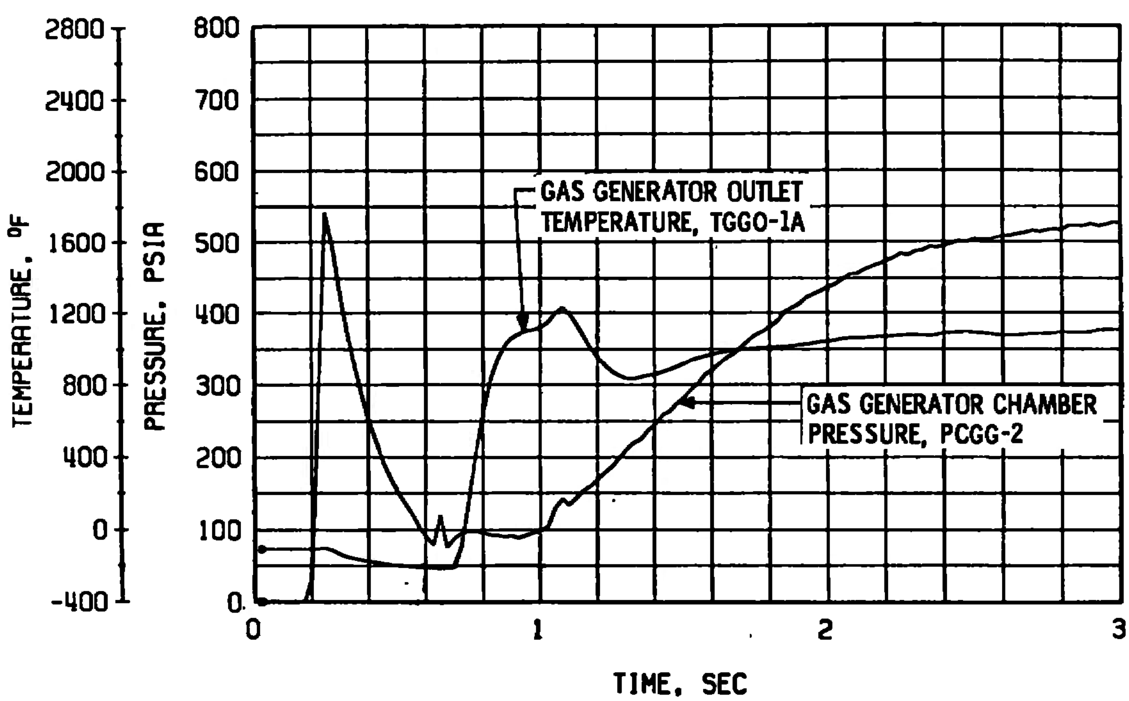


d. Thrust Chamber Oxidizer System, Shutdown

Fig. 9 Continued

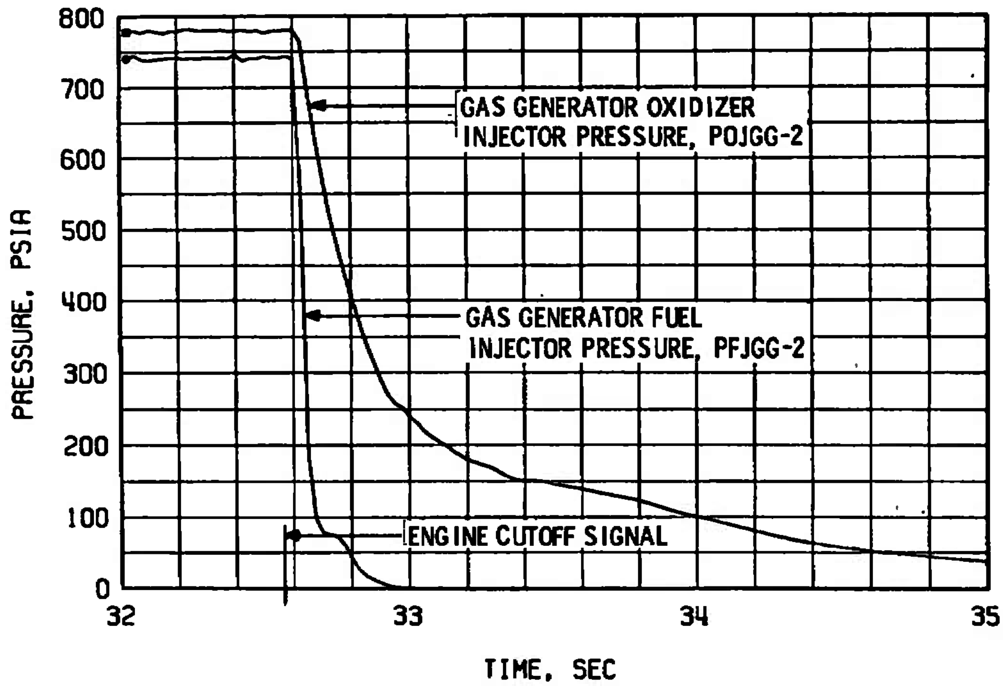


e. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

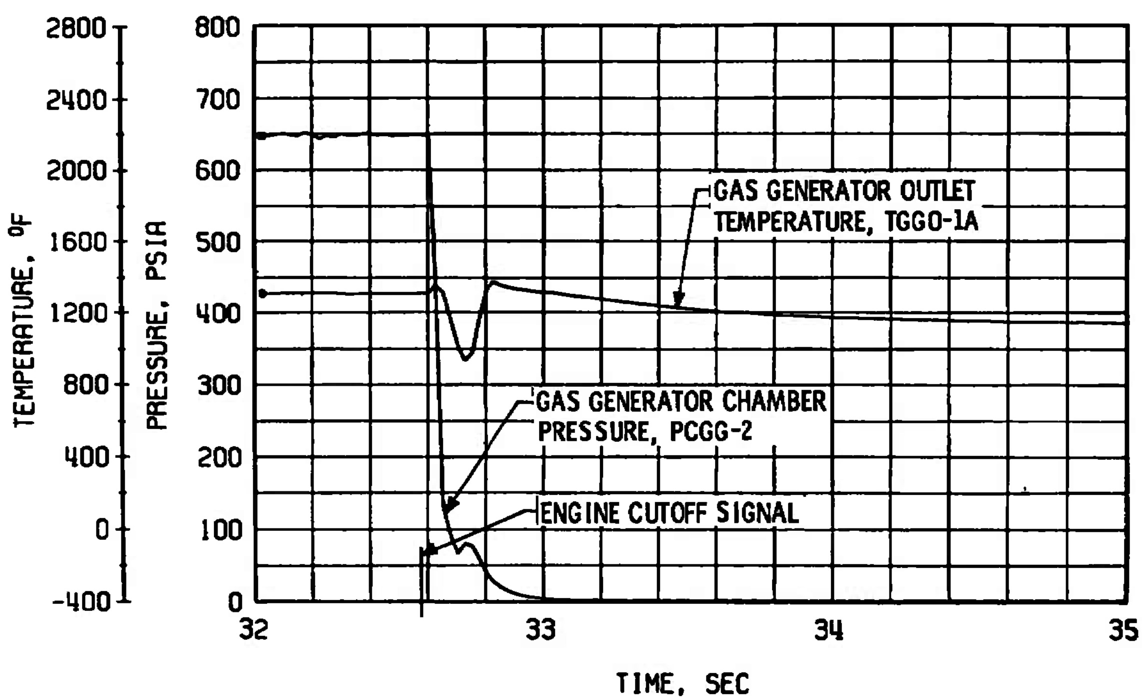


f. Gas Generator Chamber Pressure and Temperature, Start

Fig. 9 Continued



g. Gas Generator Injector Pressures, Shutdown



h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 9 Concluded

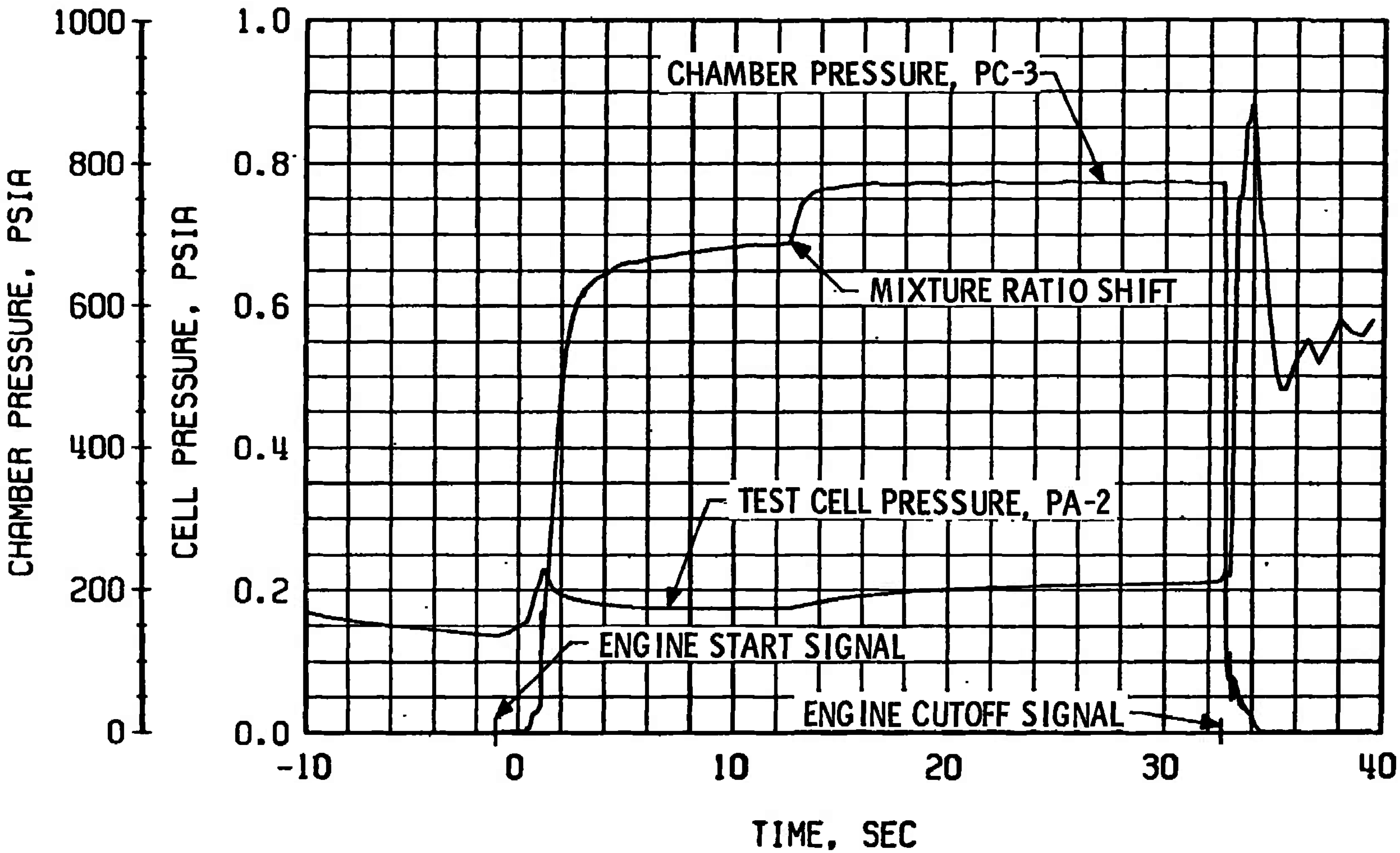
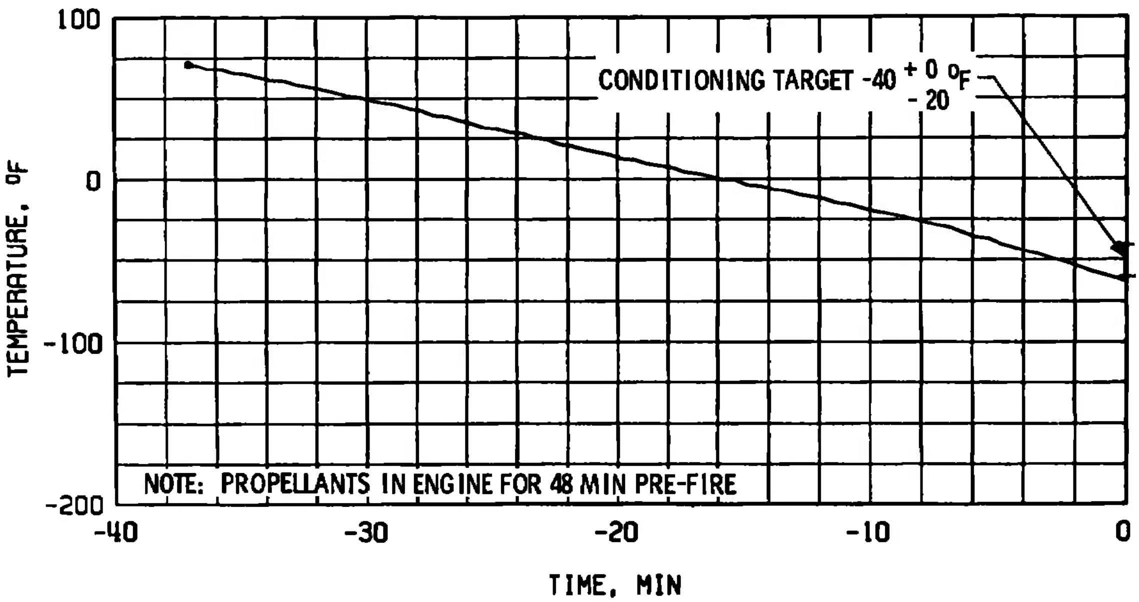
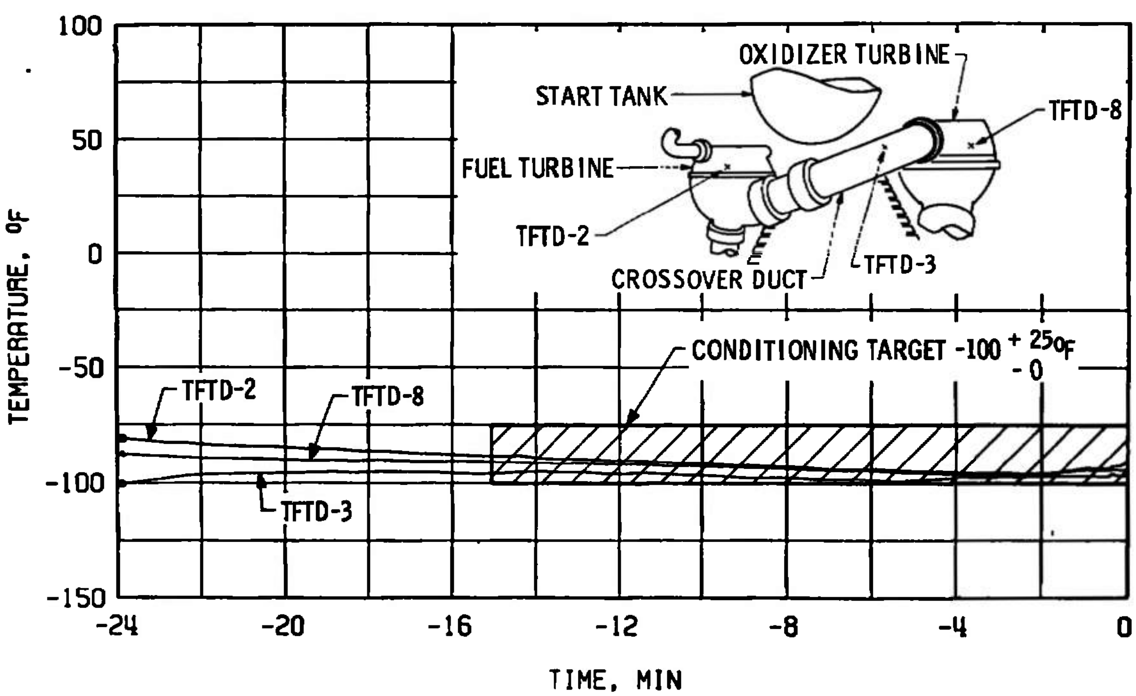


Fig. 10 Engine Ambient and Combustion Chamber Pressures, Firing 20A

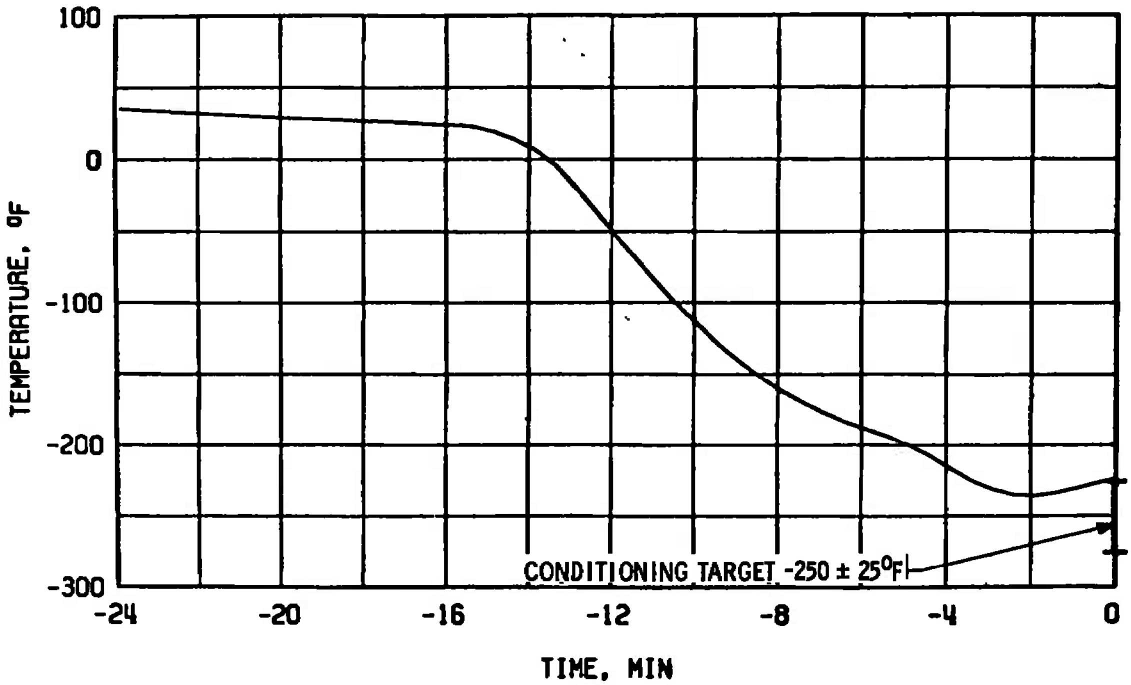


a. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

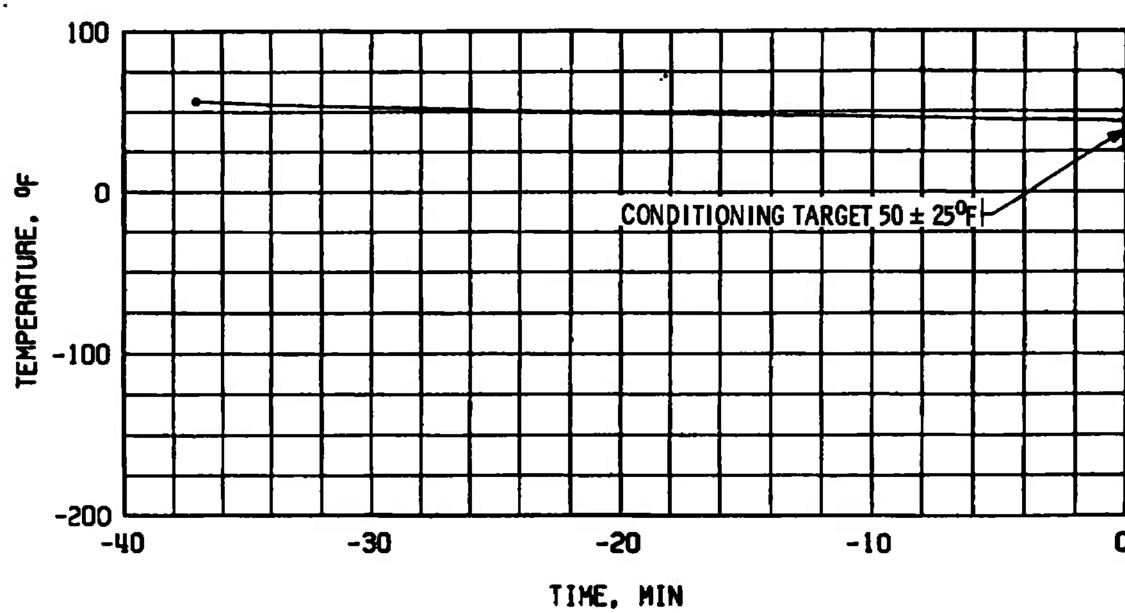


b. Crossover Duct, TFTD

Fig. 11 Thermal Conditioning History of Engine Components, Firing 20A

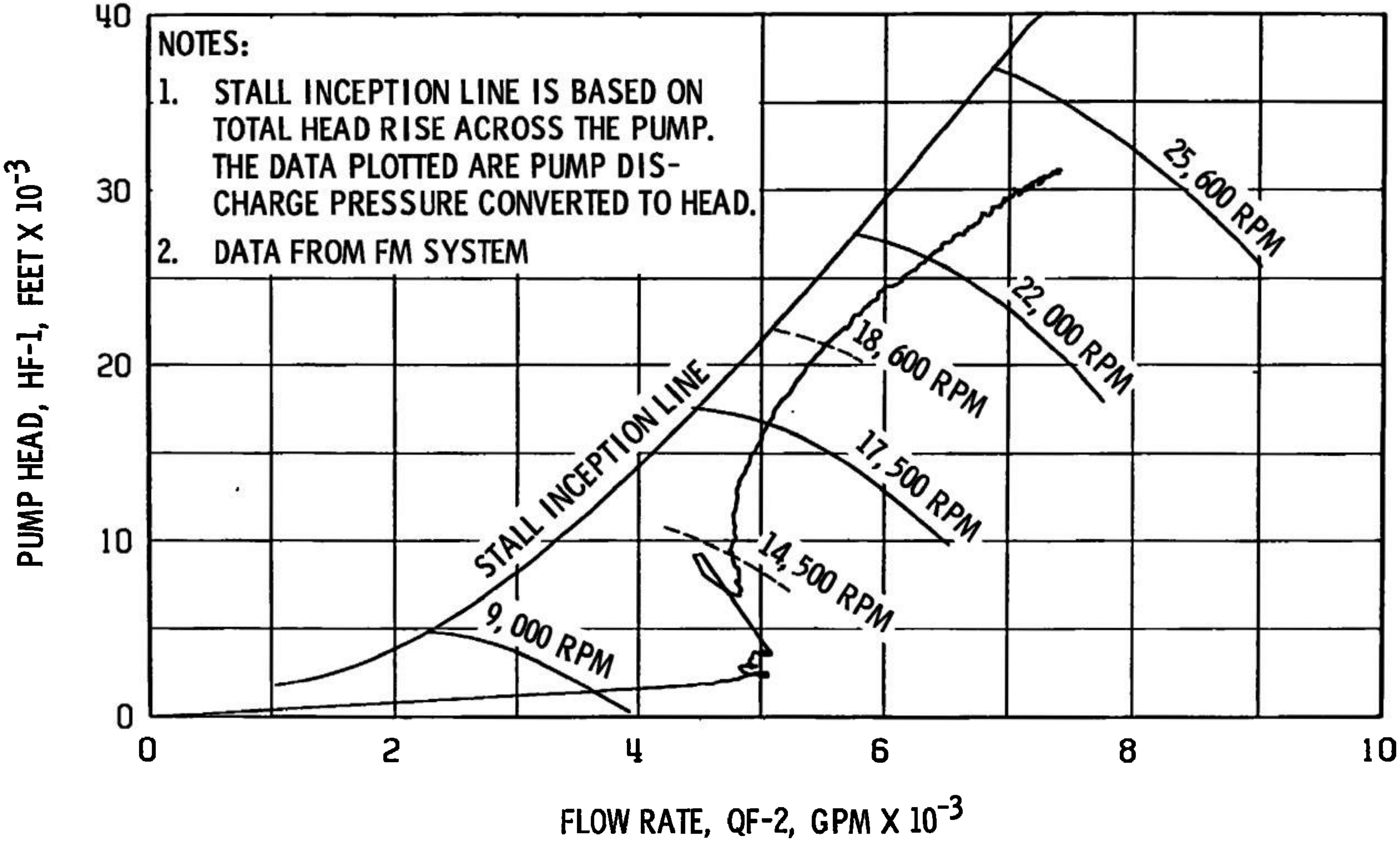


c. Thrust Chamber Throat, TTC-1P



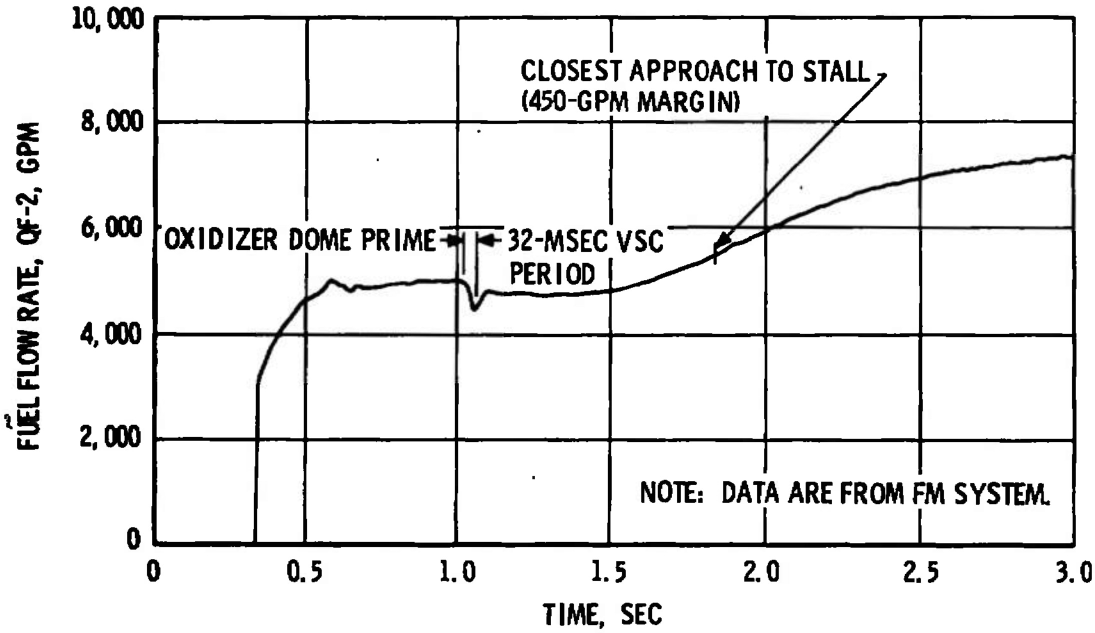
d. Start Tank Discharge Valve, TSTDVOC

Fig. 11 Concluded

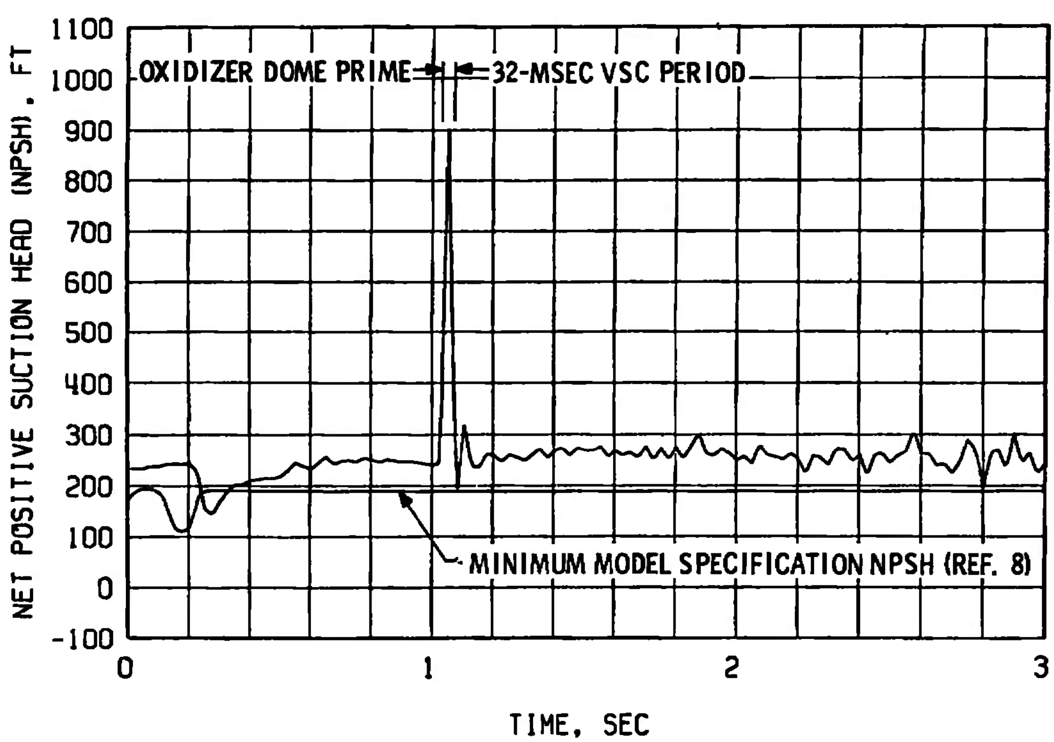


a. Fuel Pump Discharge Head-Flow Transient, Start

Fig. 12 Fuel Pump Start Transient Performance, Firing 20A

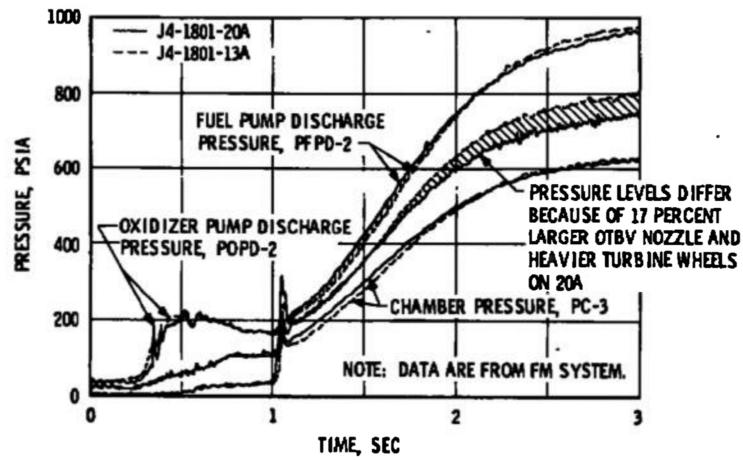


b. Fuel Pump Discharge Flow Transient, Start

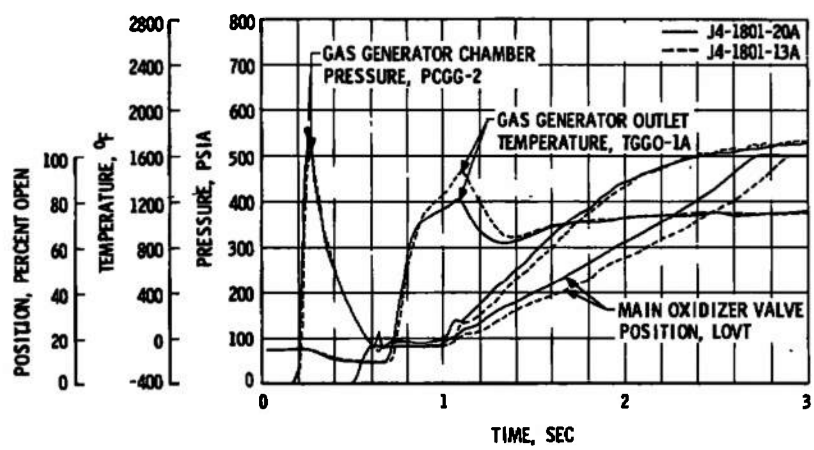


c. Fuel Pump NPSH during Start Transient

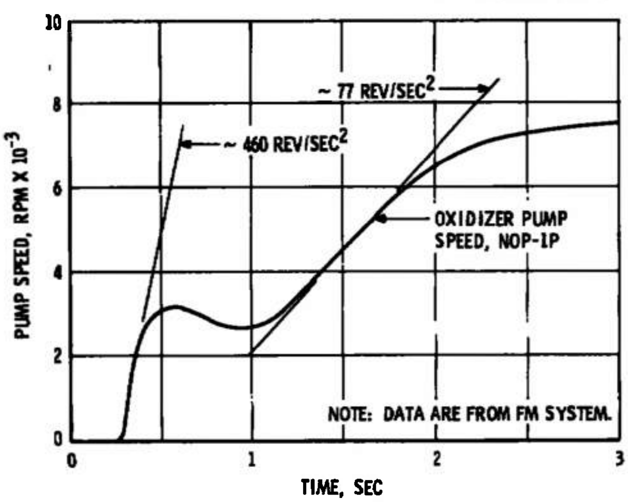
Fig. 12 Concluded



a. Oxidizer and Fuel Pump Discharge Pressures, Thrust Chamber Pressures

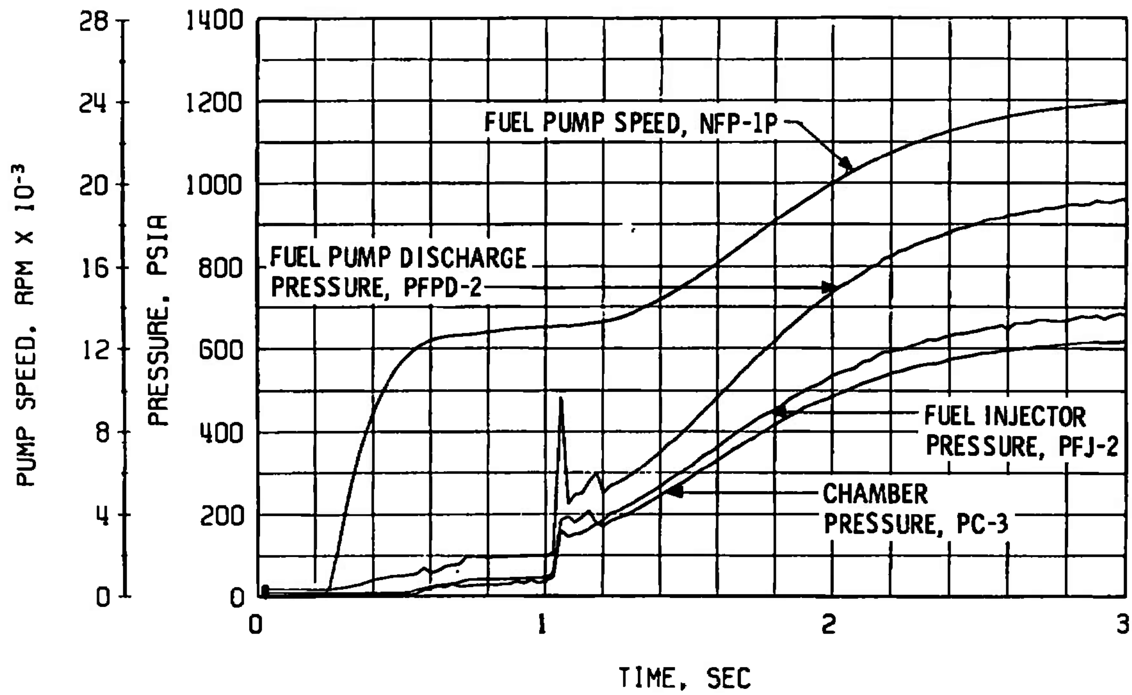


b. Gas Generator Chamber Pressures and Temperatures

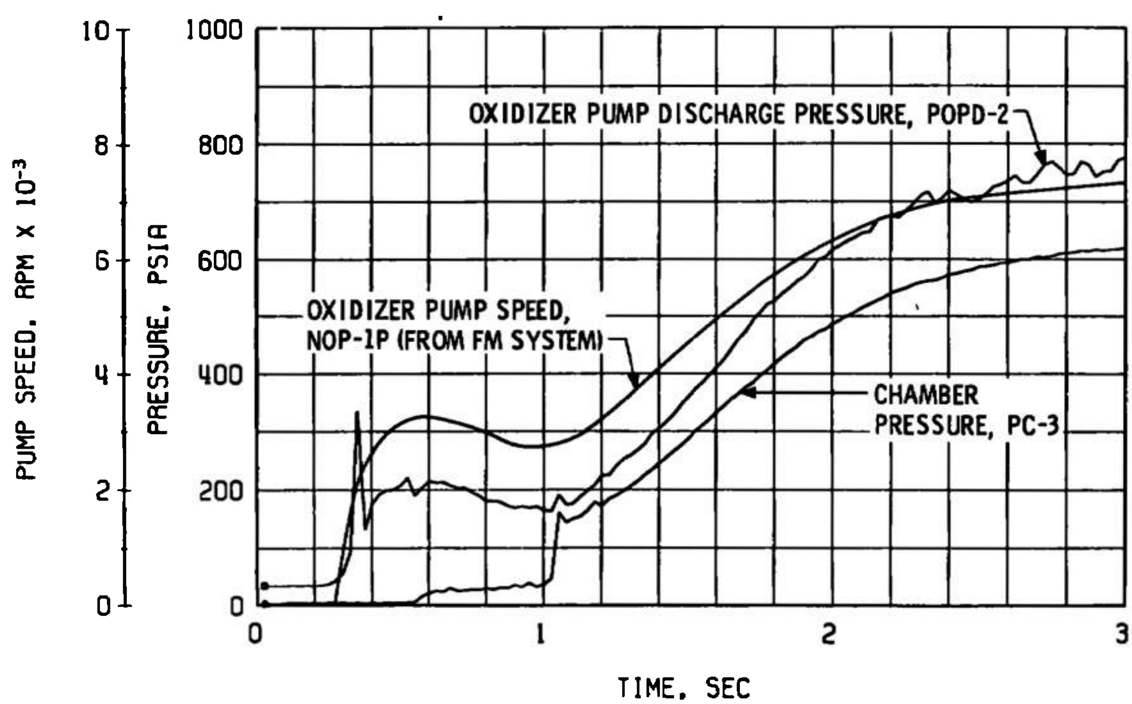


c. Oxidizer Pump Speed, Firing 13A

Fig. 13 Start Transient Comparison, Firings 20A and 13A

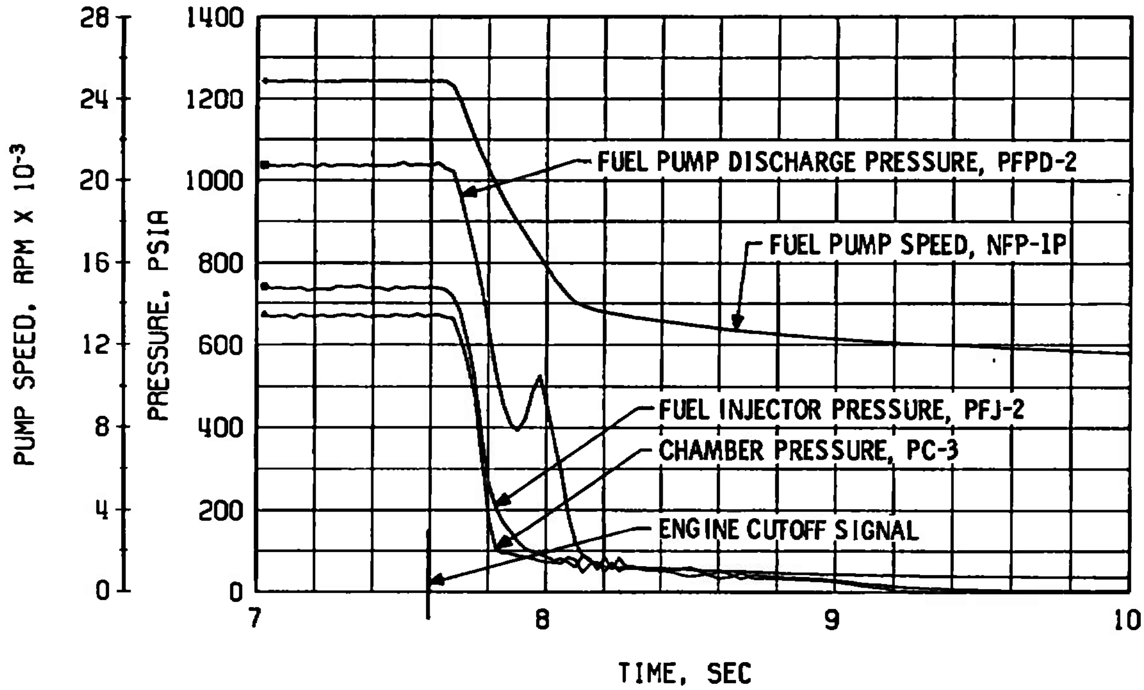


a. Thrust Chamber Fuel System, Start

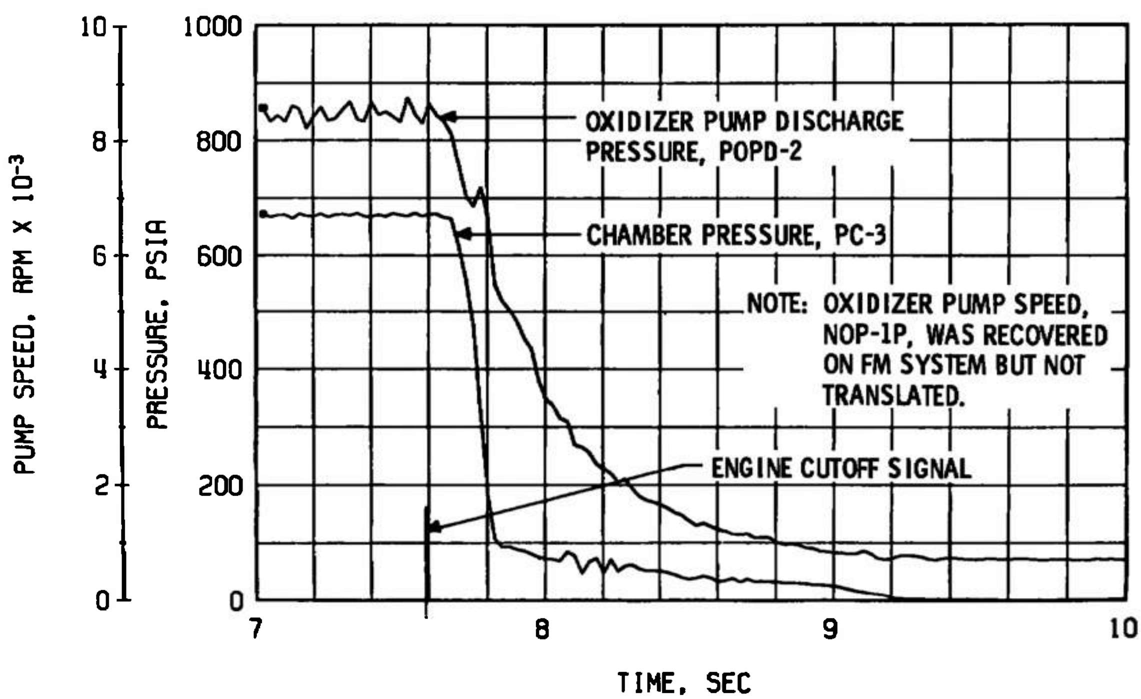


b. Thrust Chamber Oxidizer System, Start

Fig. 14 Engine Transient Operation, Firing 20B

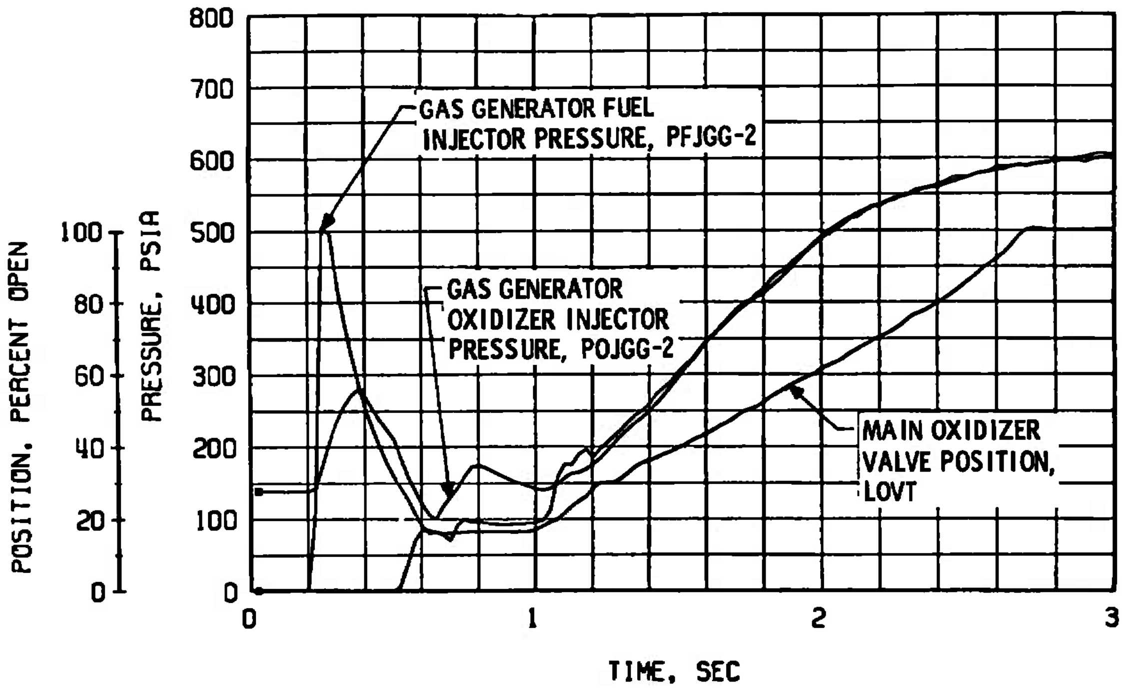


c. Thrust Chamber Fuel System, Shutdown

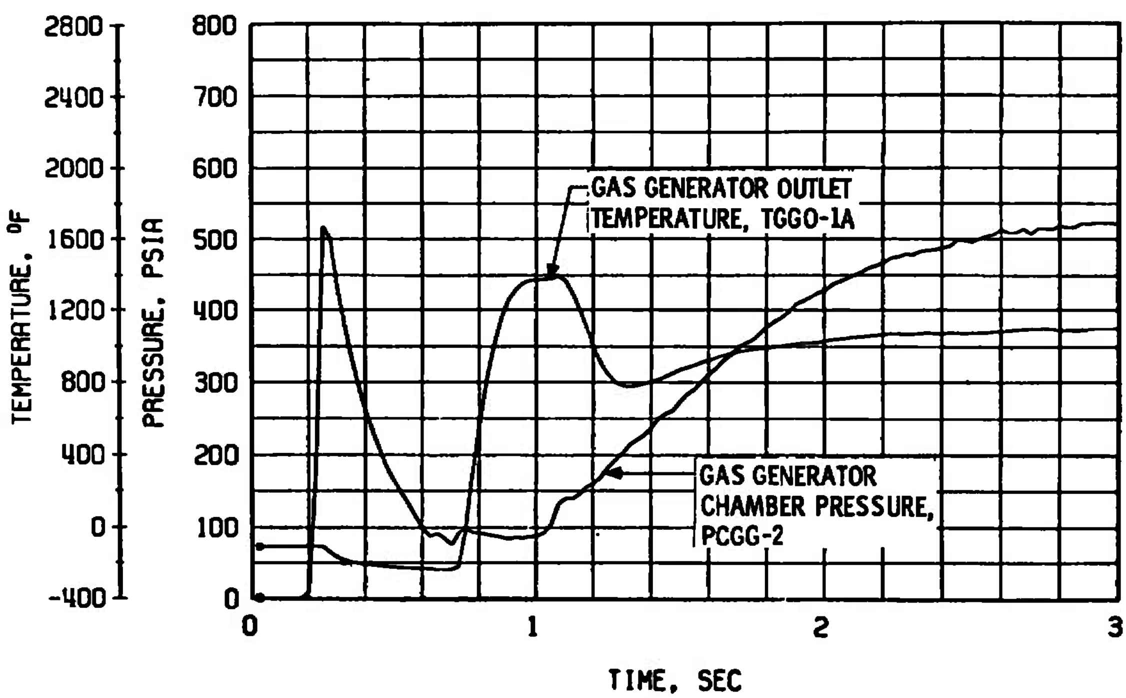


d. Thrust Chamber Oxidizer System, Shutdown

Fig. 14 Continued

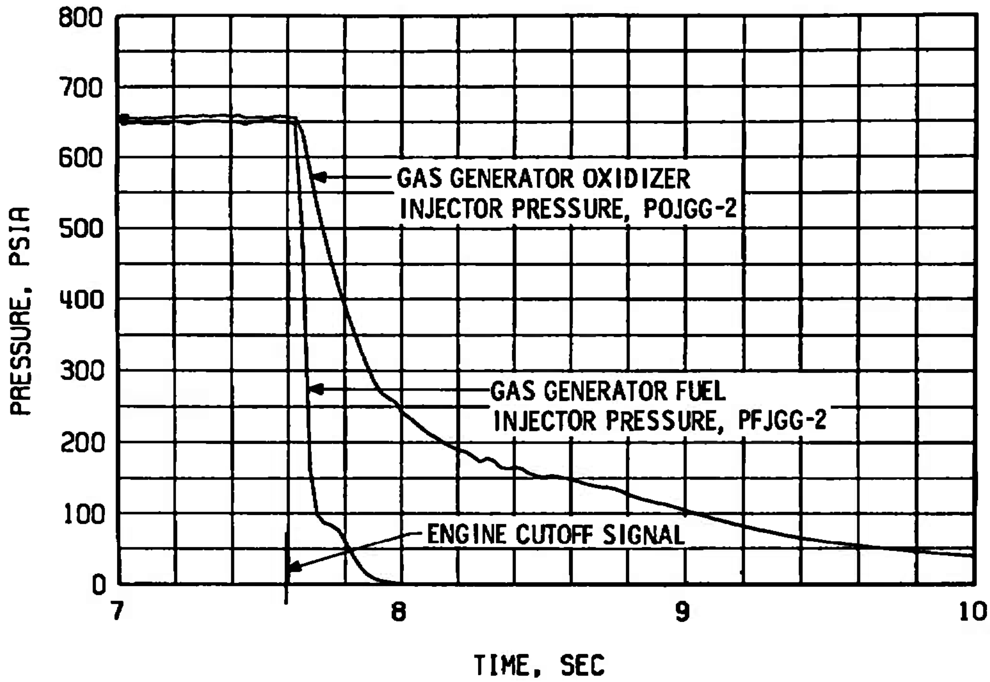


e. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

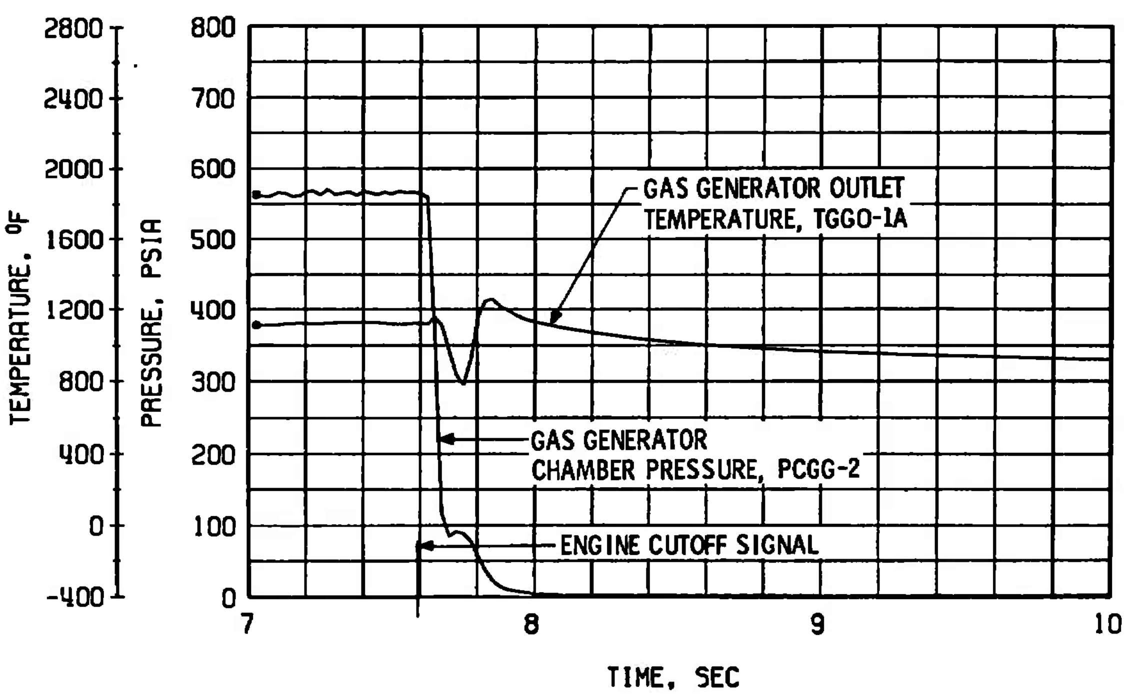


f. Gas Generator Chamber Pressure and Temperature, Start

Fig. 14 Continued



g. Gas Generator Injector Pressures, Shutdown



h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 14 Concluded

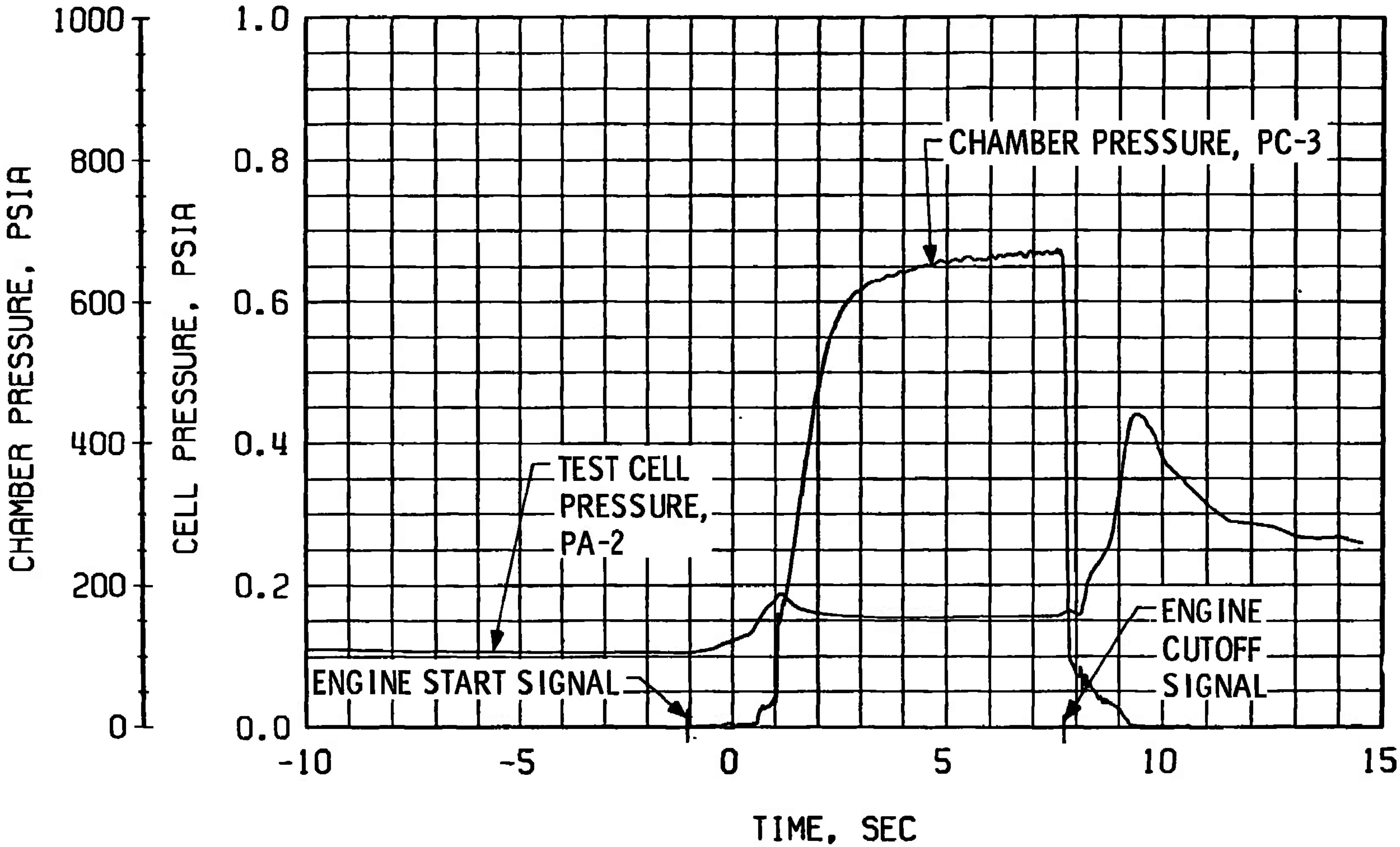
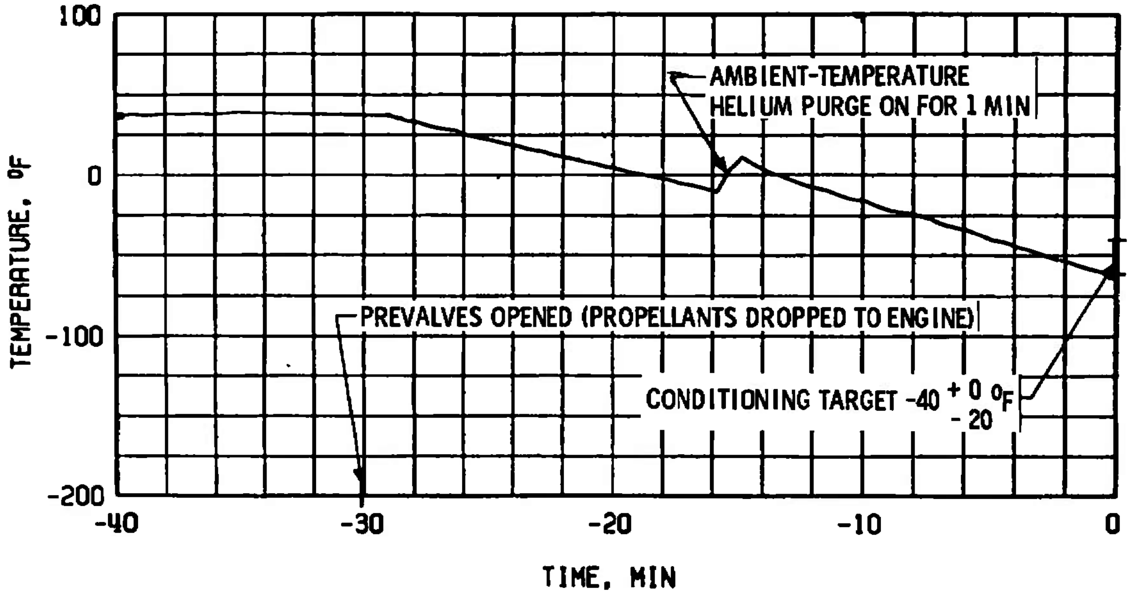
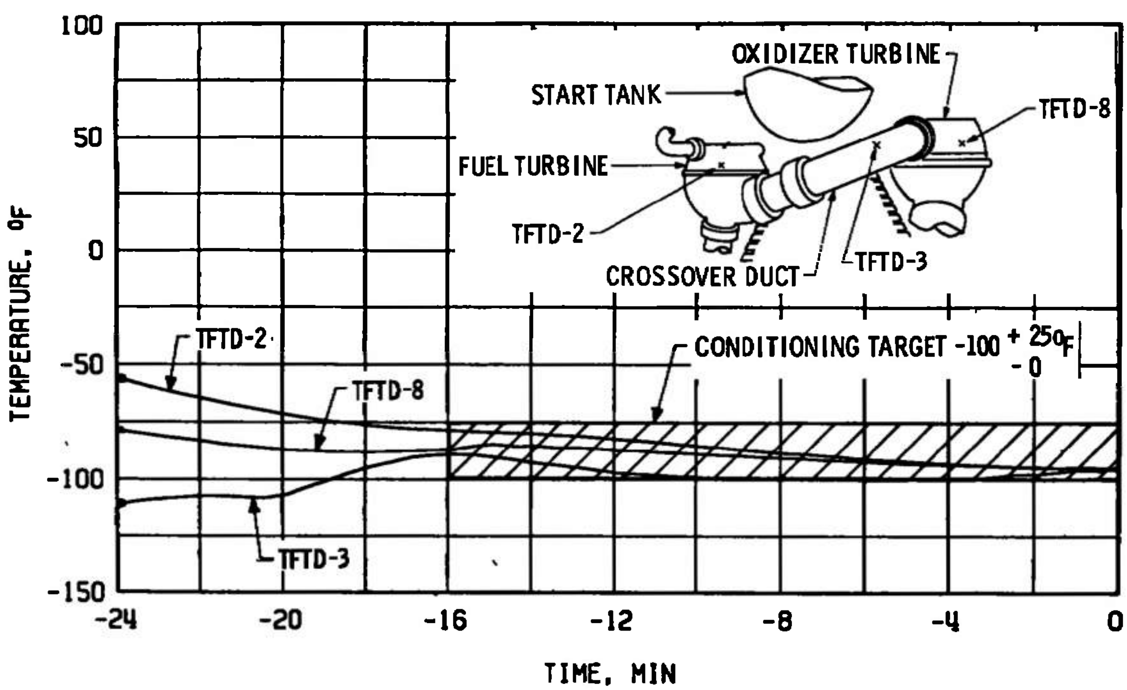


Fig. 15 Engine Ambient and Combustion Chamber Pressures, Firing 20B

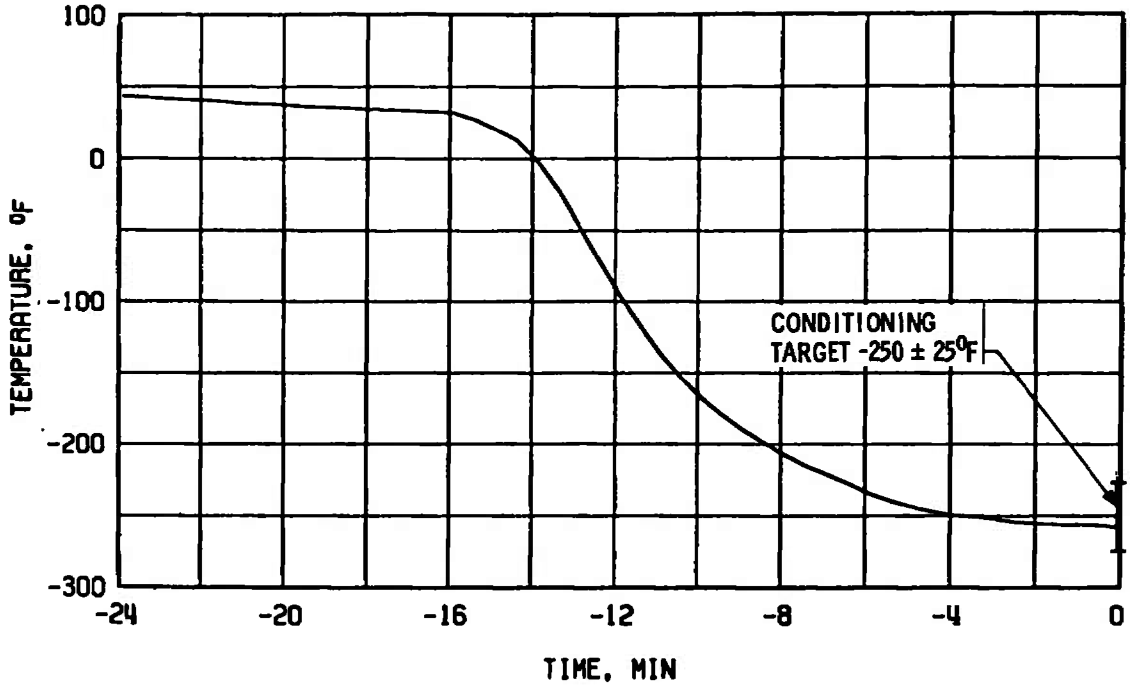


a. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

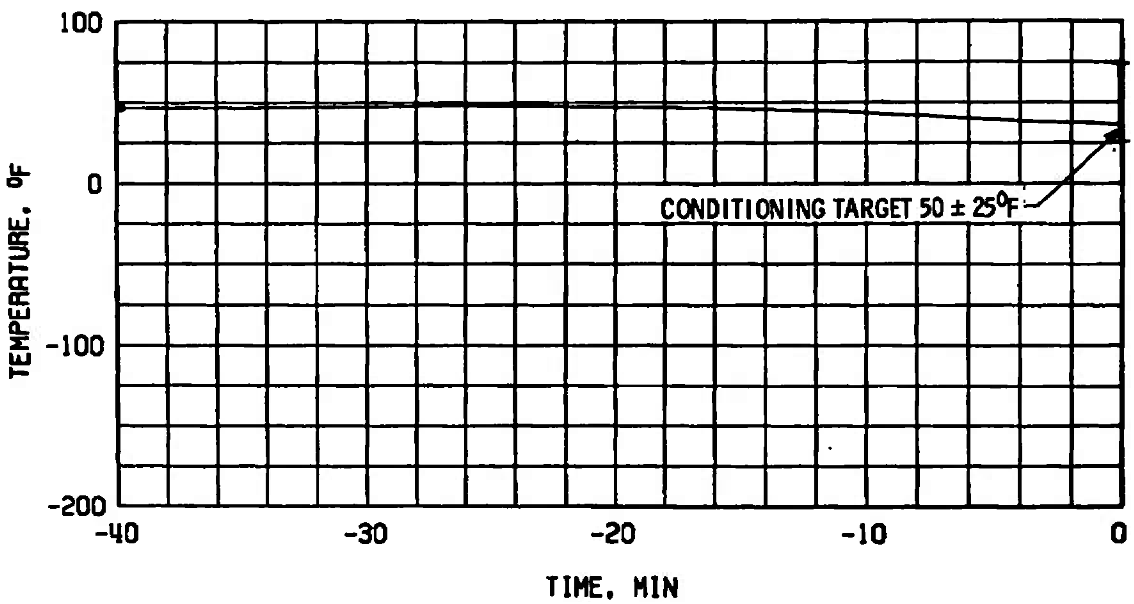


b. Crossover Duct, TFTD

Fig. 16 Thermal Conditioning History of Engine Components, Firing 20B

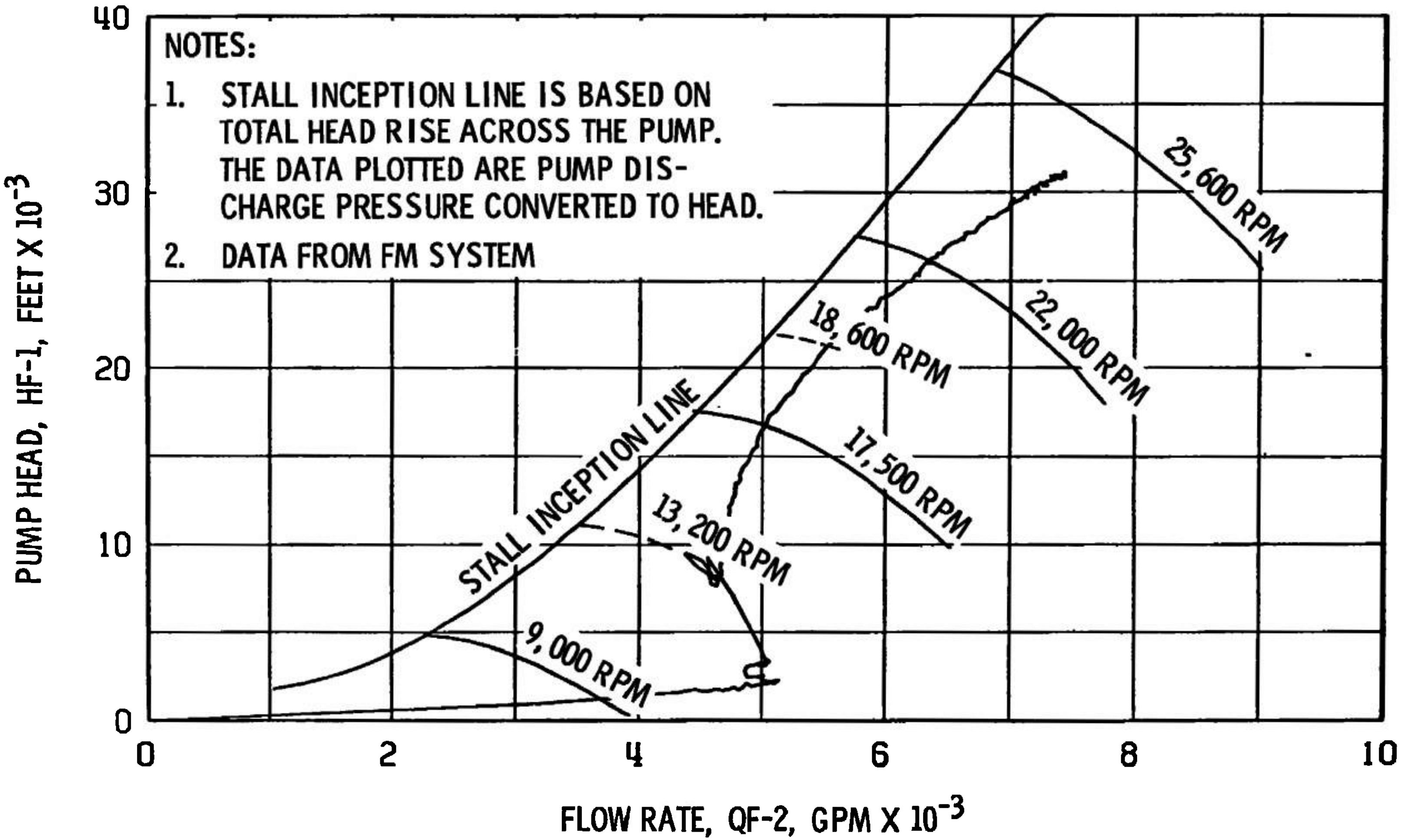


c. Thrust Chamber Throat, TTC-1P



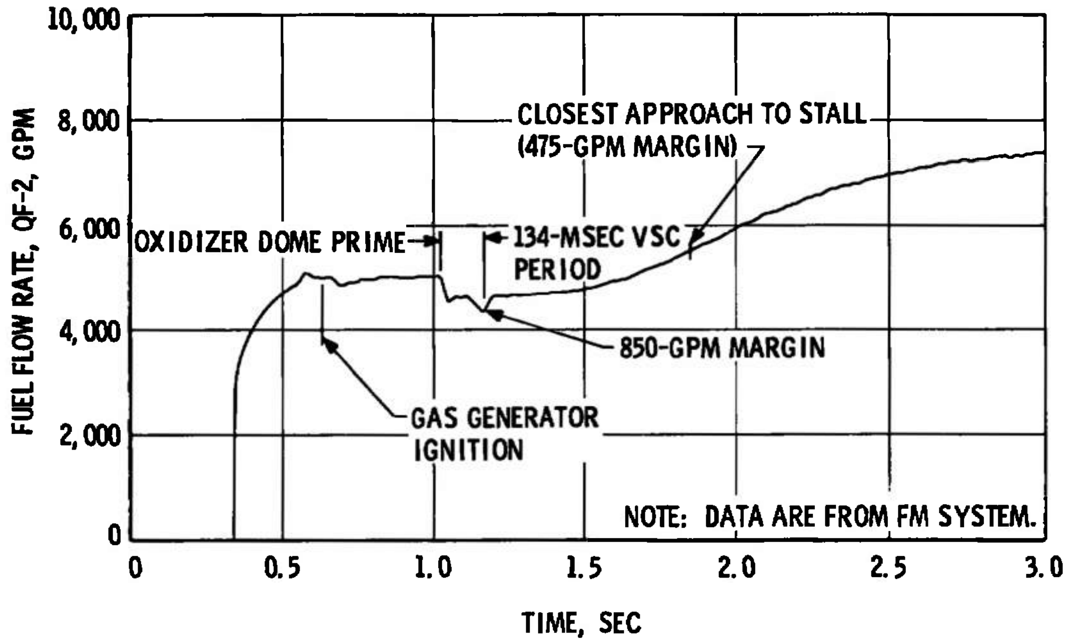
d. Start Tank Discharge Valve, TSTDVOC

Fig. 16 Concluded

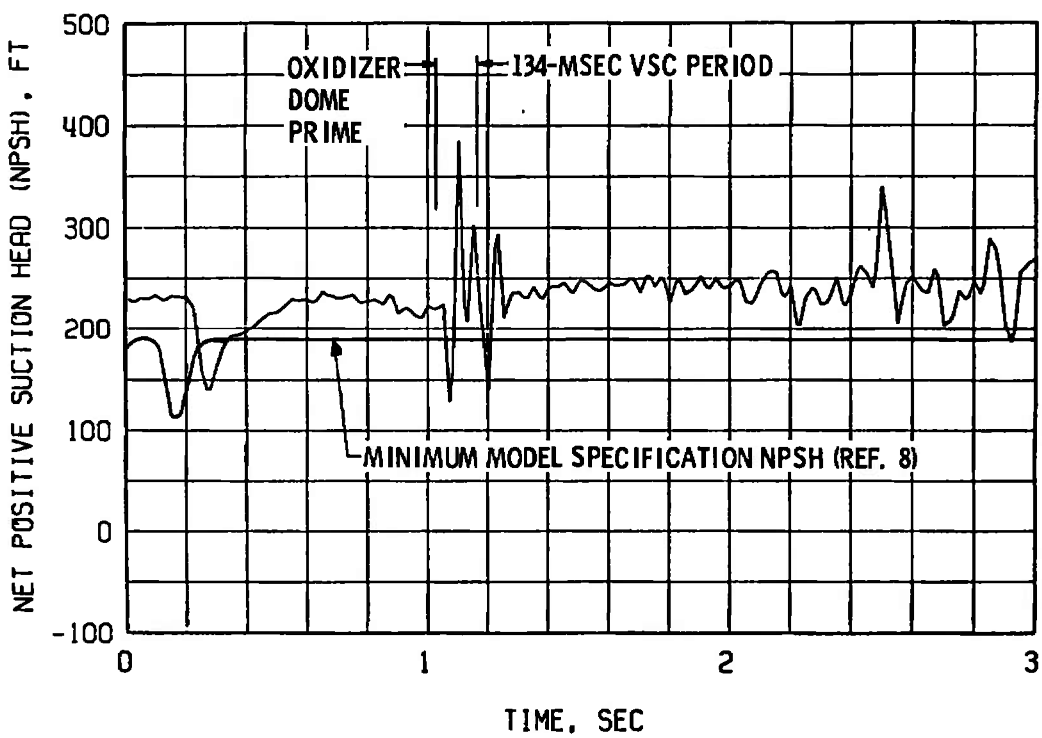


a. Fuel Pump Discharge Head-Flow Transient, Start

Fig. 17 Fuel Pump Start Transient Performance, Firing 20B

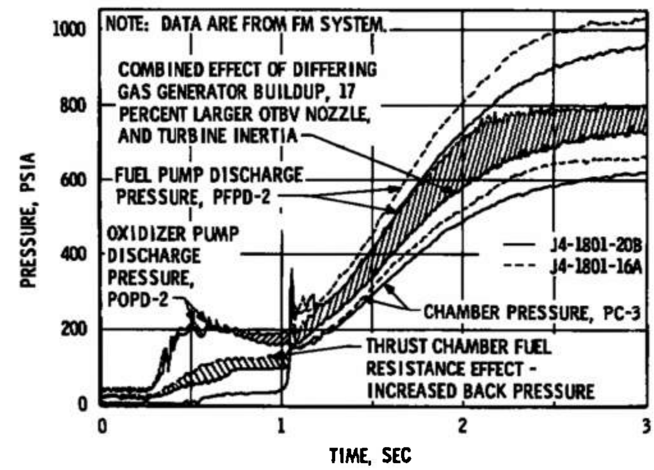


b. Fuel Pump Discharge Flow Transient, Start

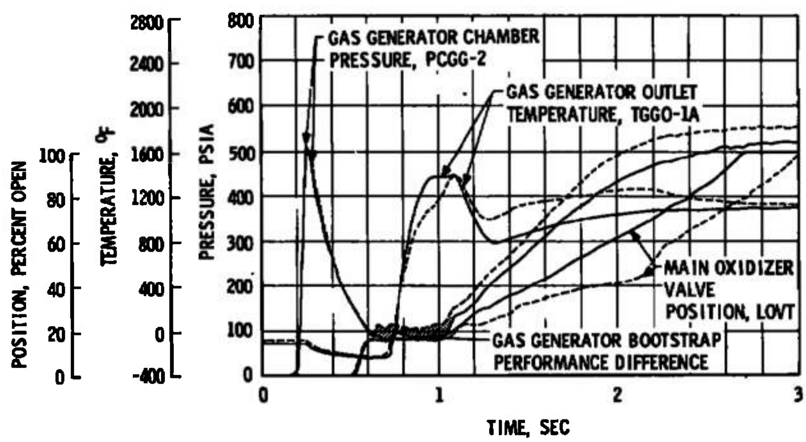


c. Fuel Pump NPSH during Start Transient

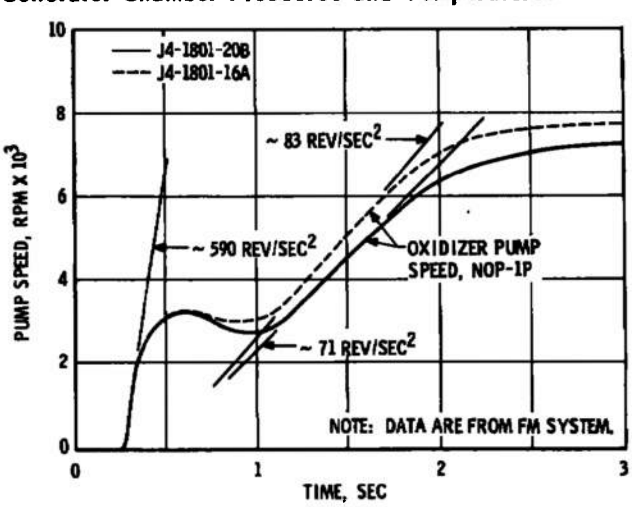
Fig. 17 Concluded



a. Oxidizer and Fuel Pump Discharge Pressures, Thrust Chamber Pressures

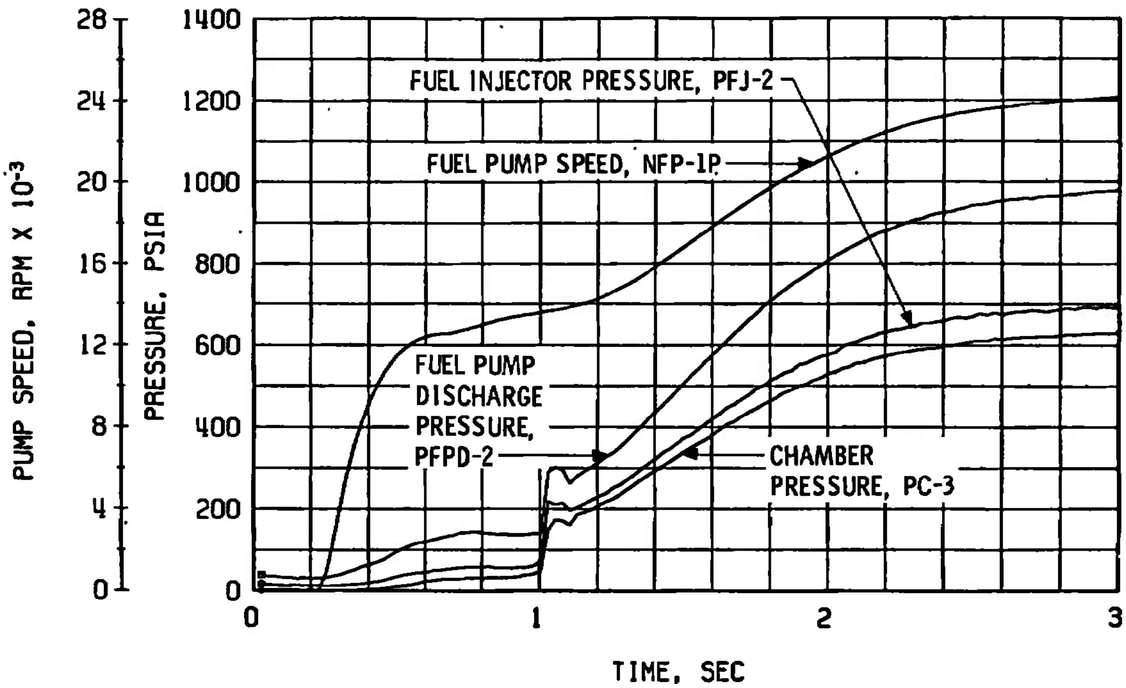


b. Gas Generator Chamber Pressures and Temperatures

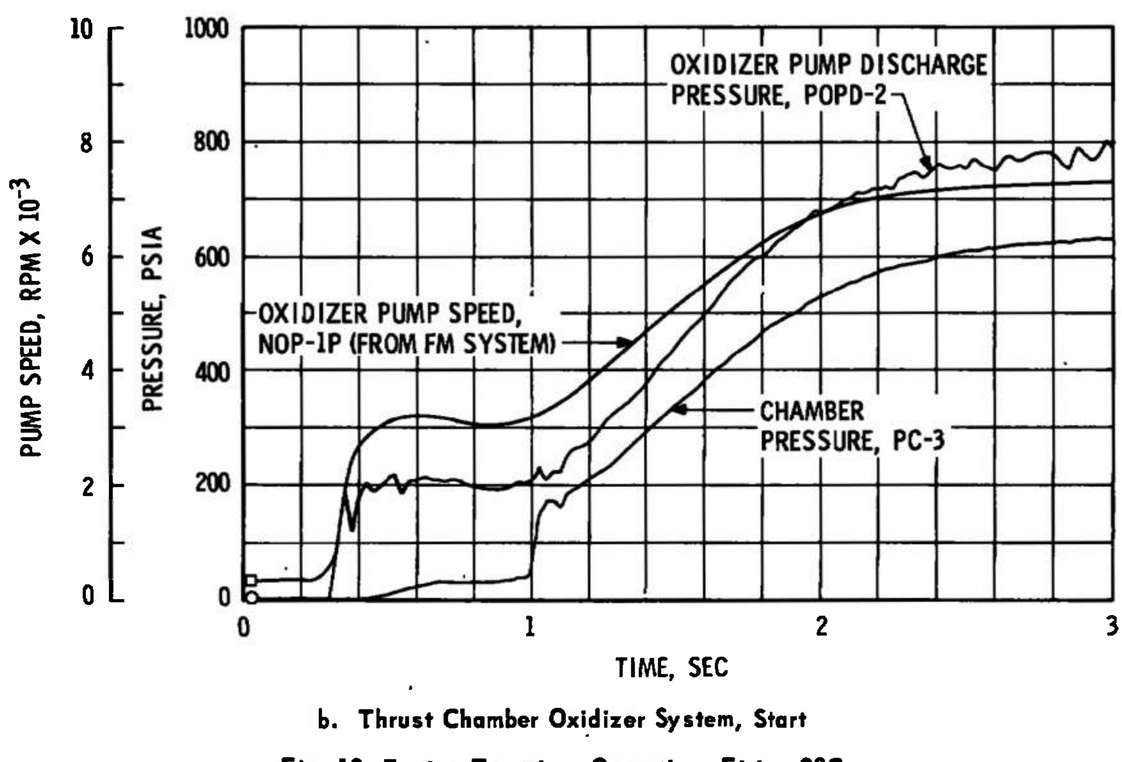


c. Oxidizer Pump Speeds

Fig. 18 Start Transient Comparison, Firings 20B and 16A

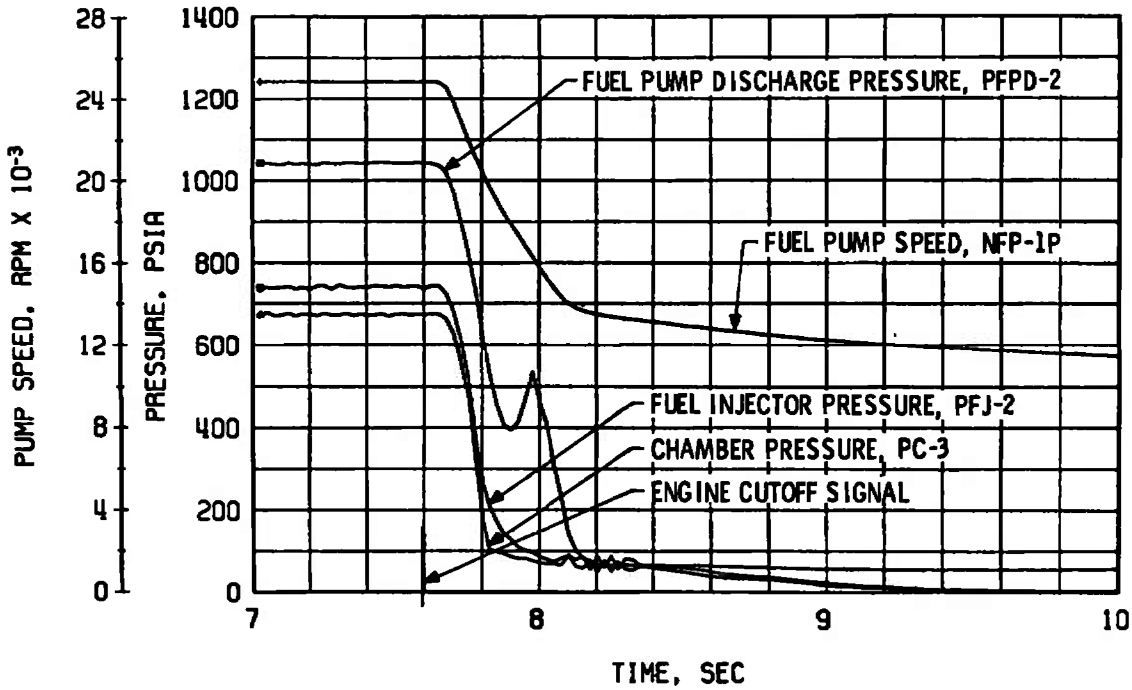


a. Thrust Chamber Fuel System, Start

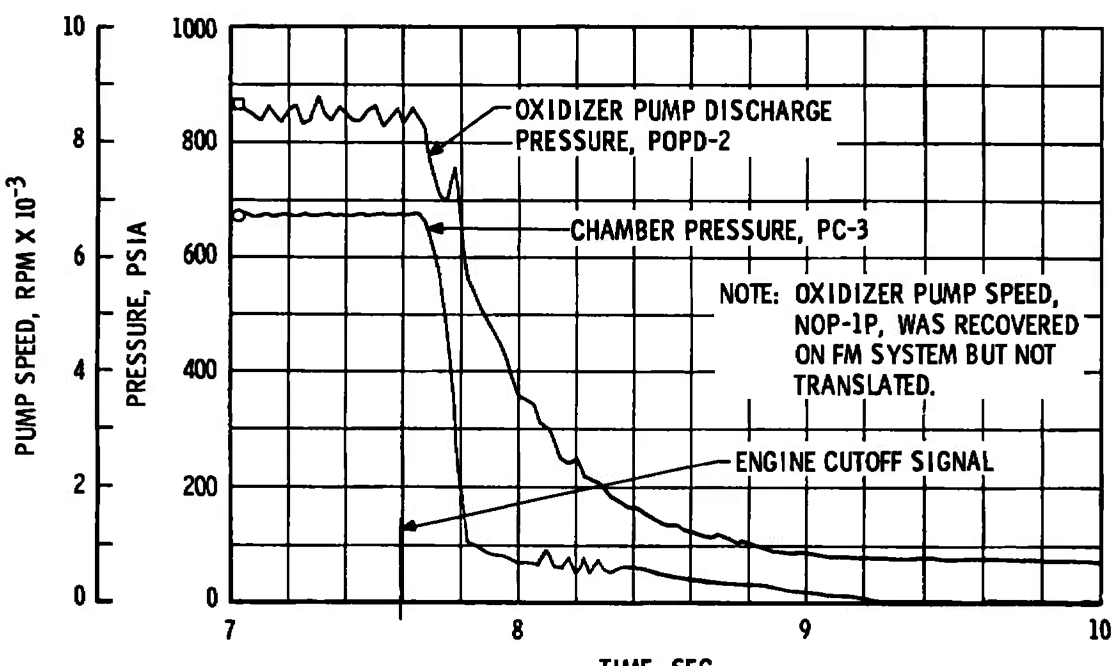


b. Thrust Chamber Oxidizer System, Start

Fig. 19 Engine Transient Operation, Firing 20C

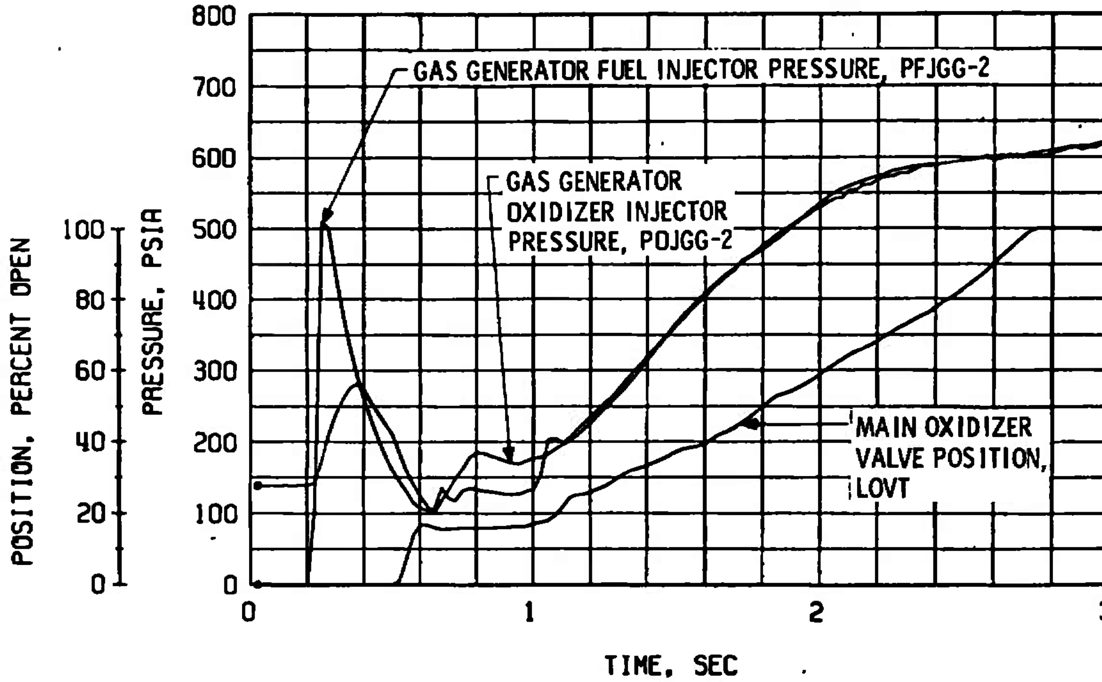


c. Thrust Chamber Fuel System, Shutdown

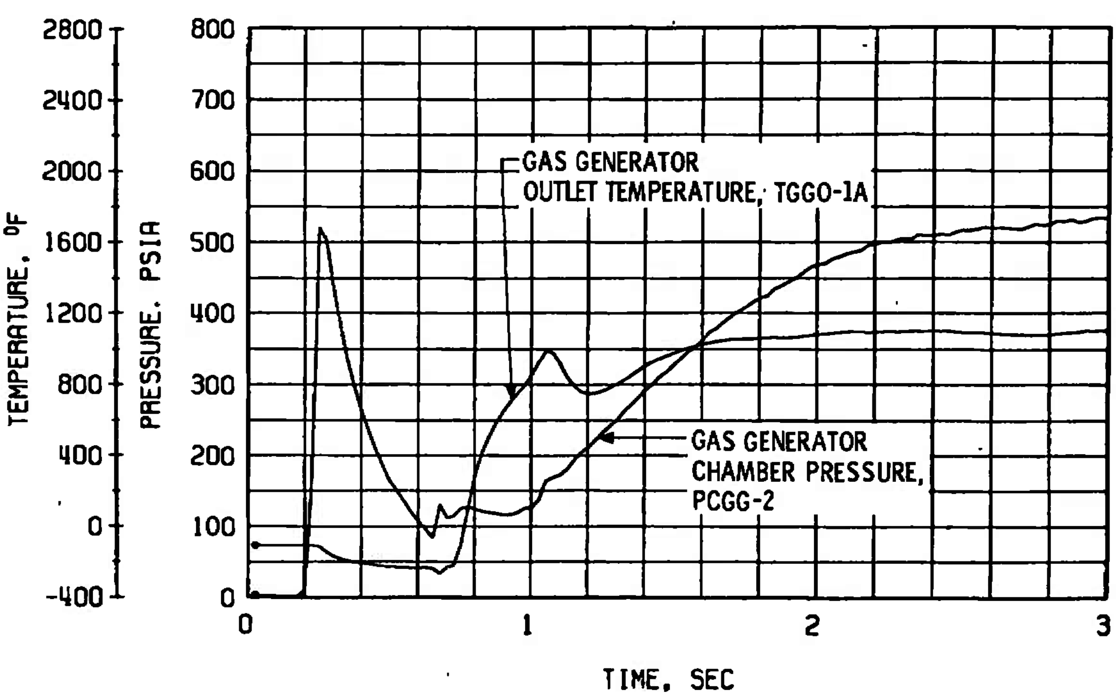


d. Thrust Chamber Oxidizer System, Shutdown

Fig. 19 Continued

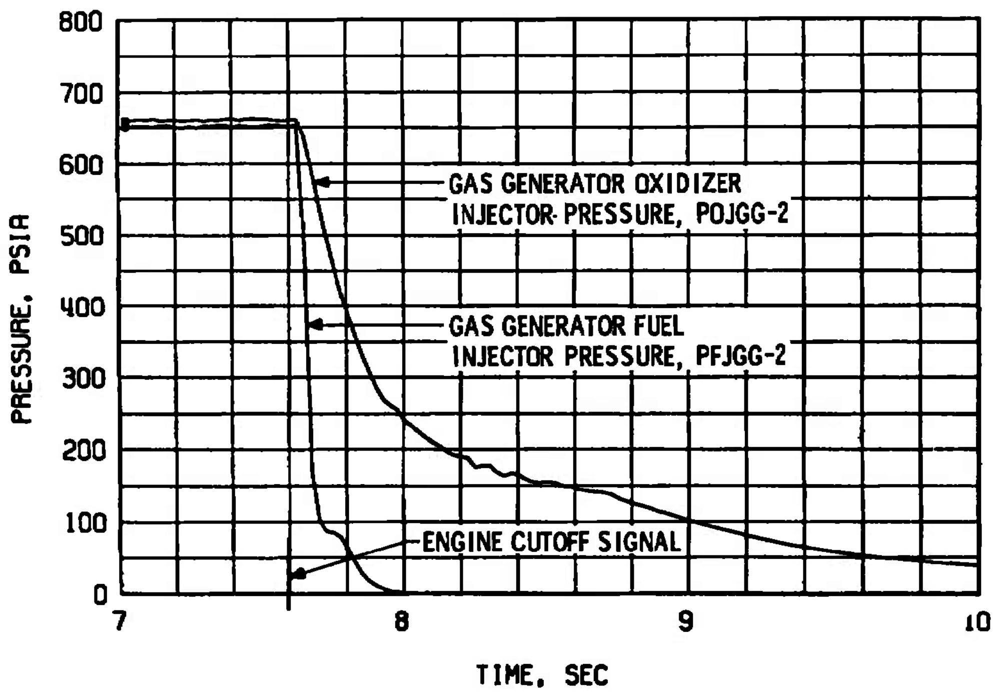


e. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

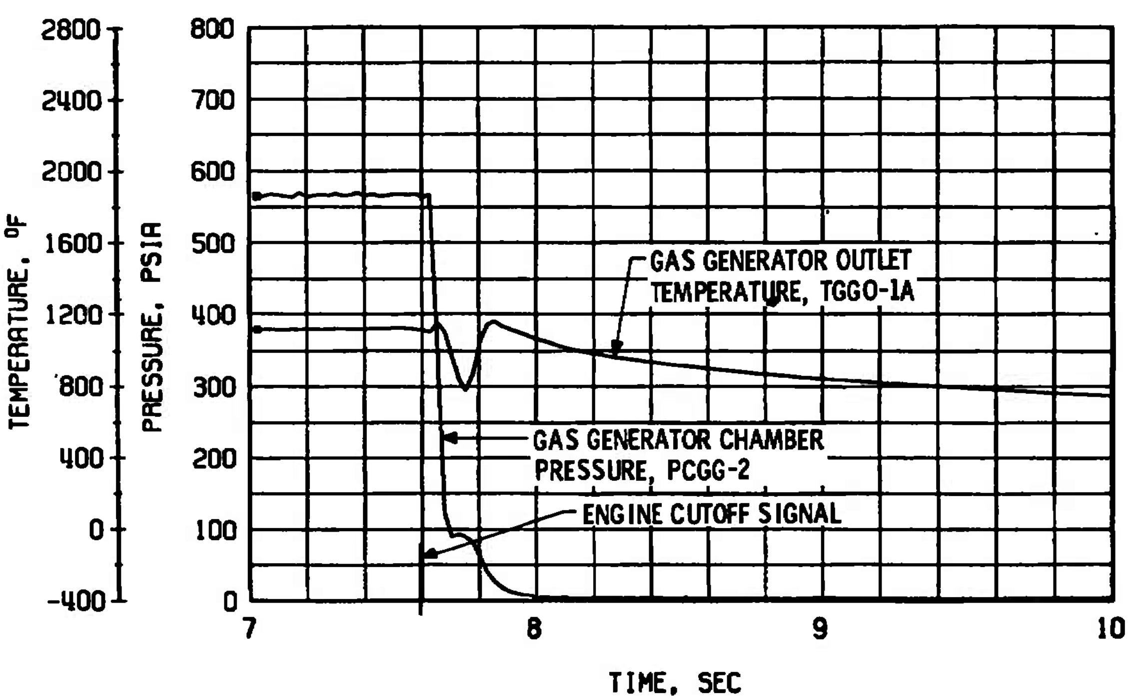


f. Gas Generator Chamber Pressures and Temperature, Start

Fig. 19 Continued



g. Gas Generator Injector Pressures, Shutdown



h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 19 Concluded

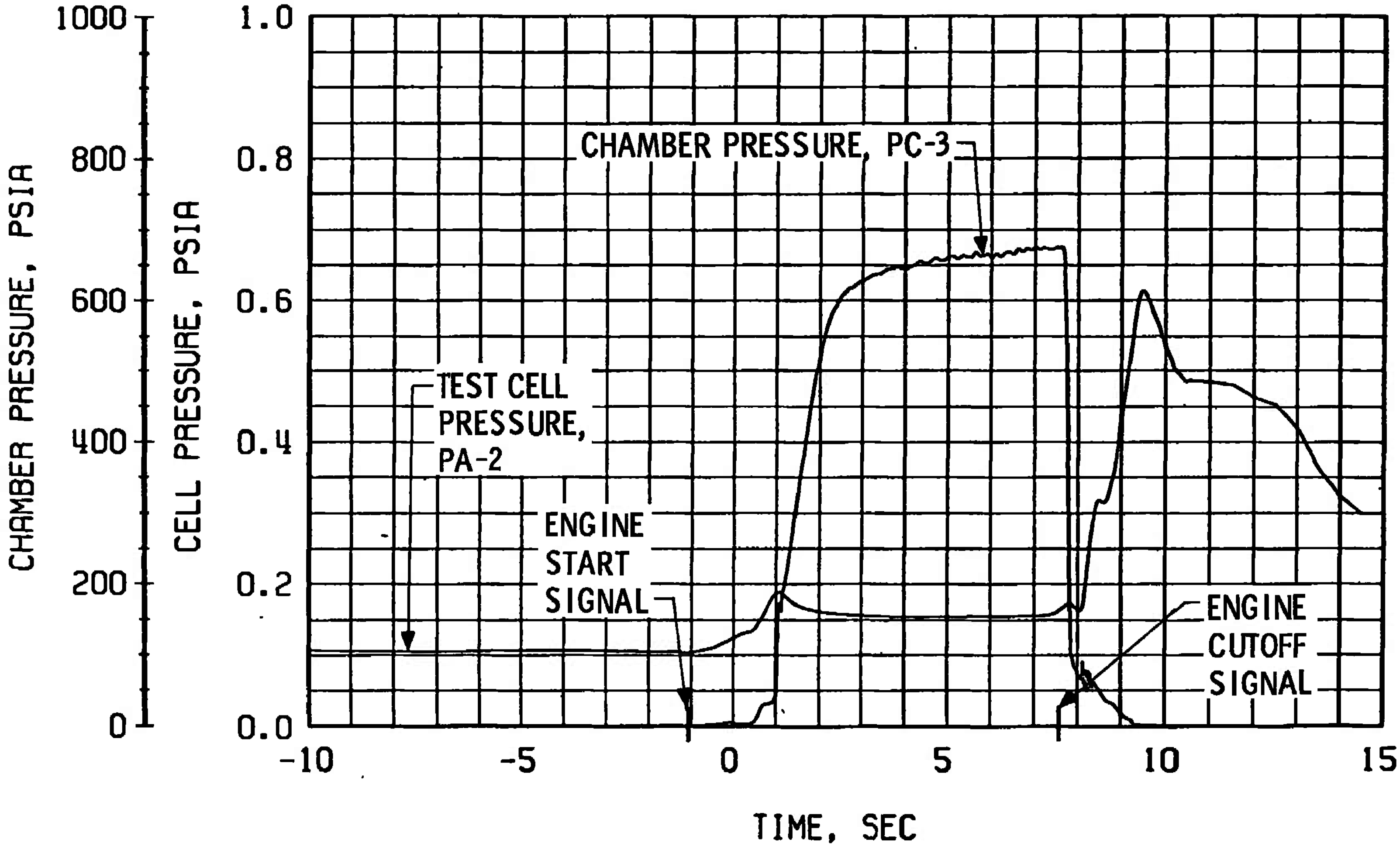
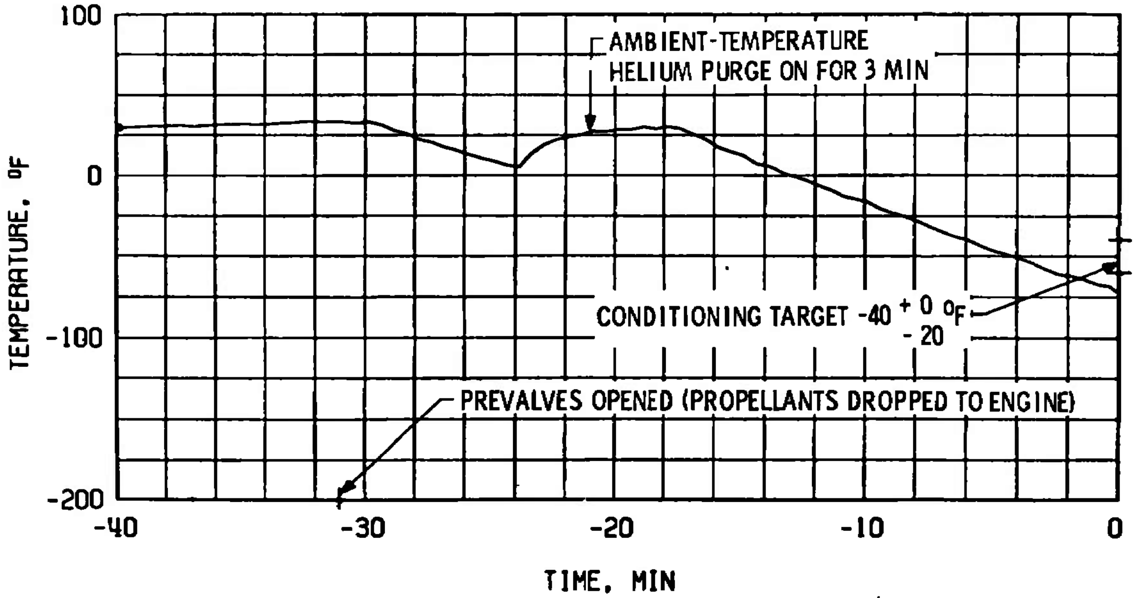
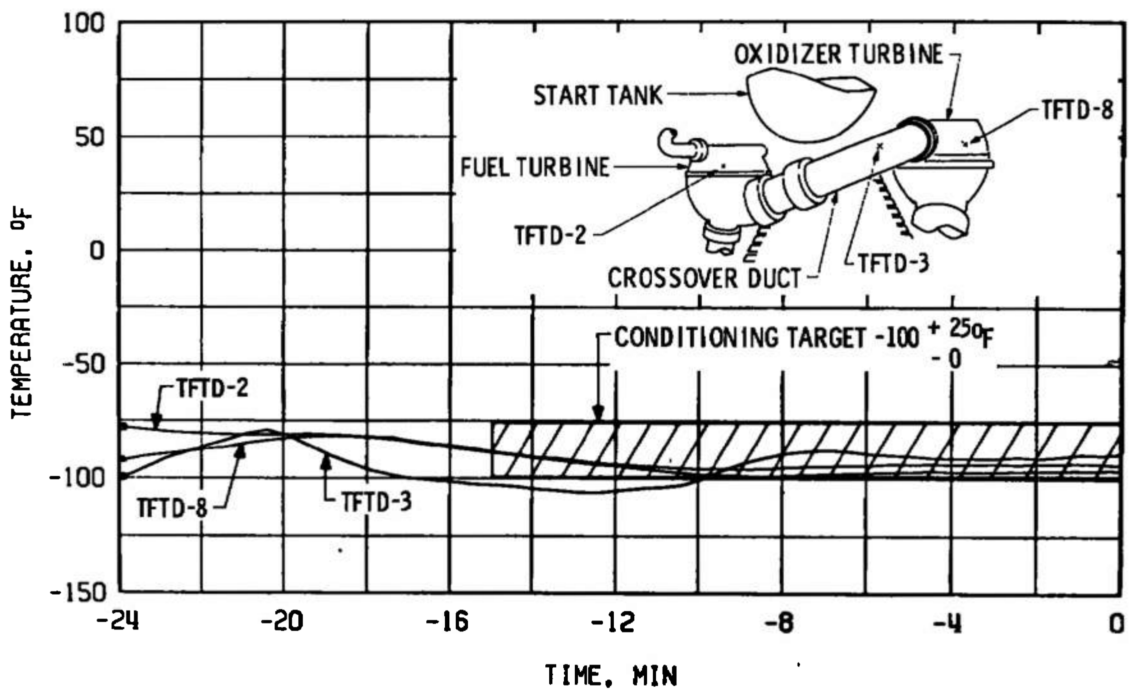


Fig. 20 Engine Ambient and Combustion Chamber Pressures, Firing 20C

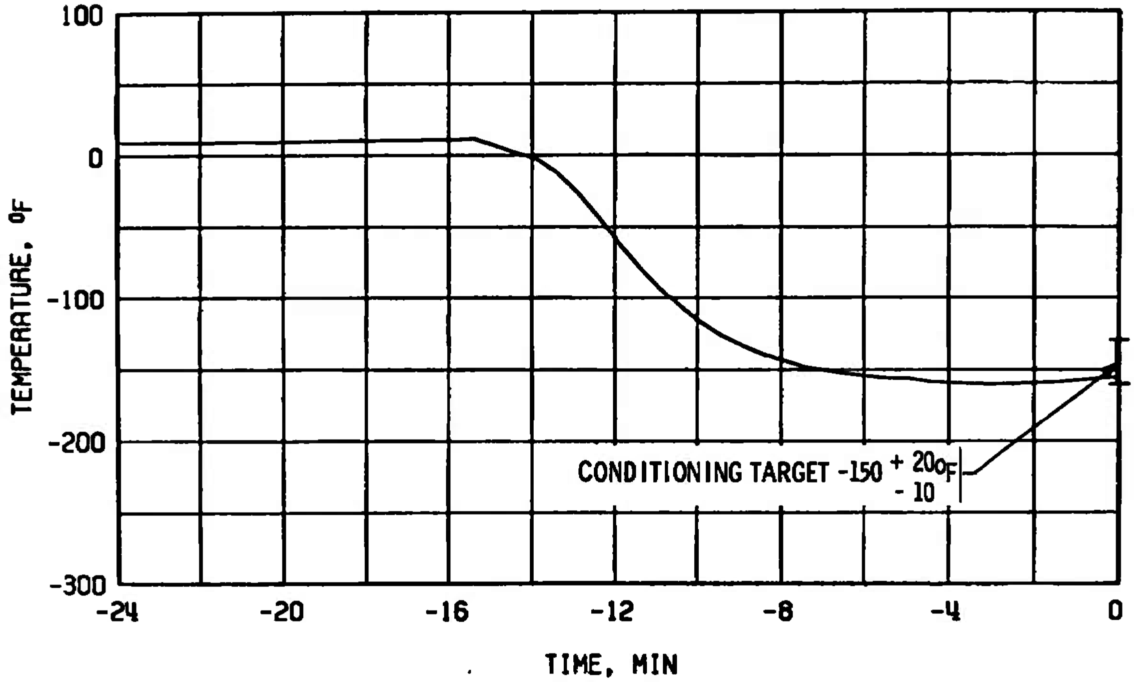


a. Main Oxidizer Valve Second-Stage Actuator

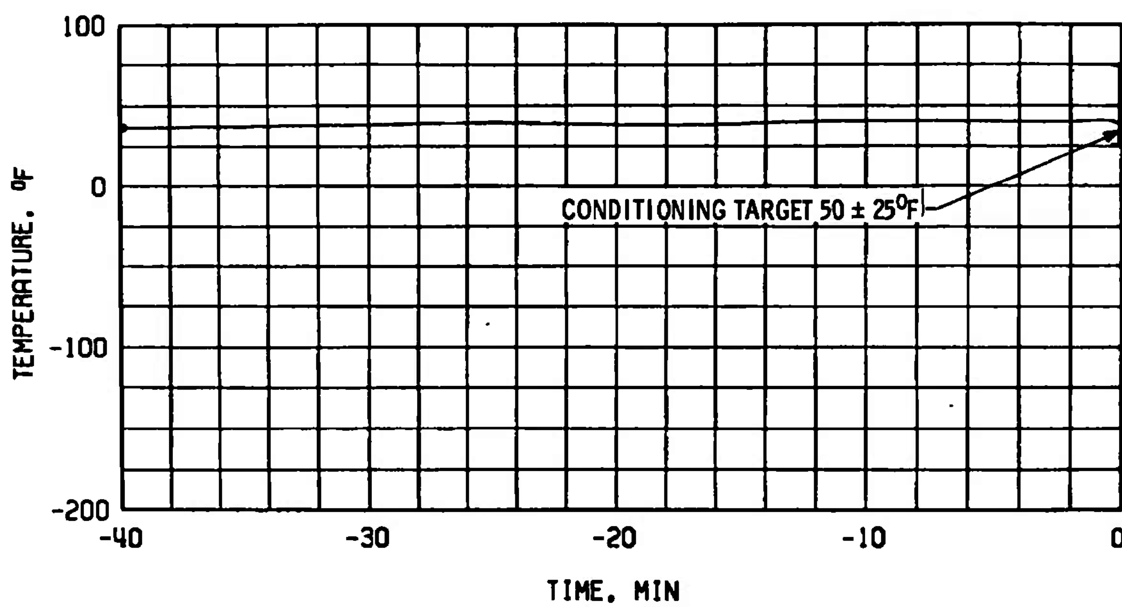


b. Crossover Duct, TFTD

Fig. 21 Thermal Conditioning History of Engine Components, Firing 20C



c. Thrust Chamber Throat, TTC-1P



d. Start Tank Discharge Valve, TSTDVOC

Fig. 21 Concluded

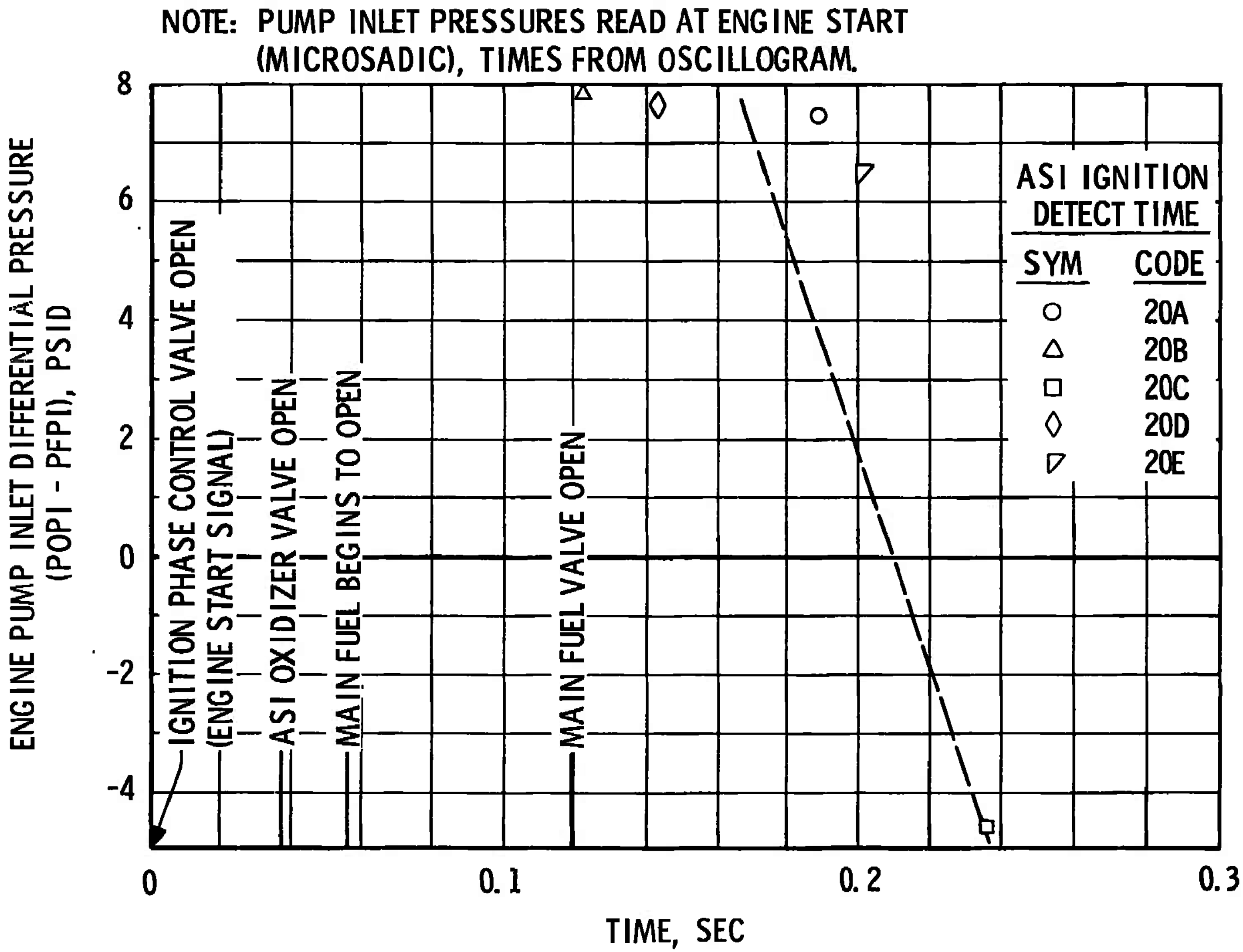
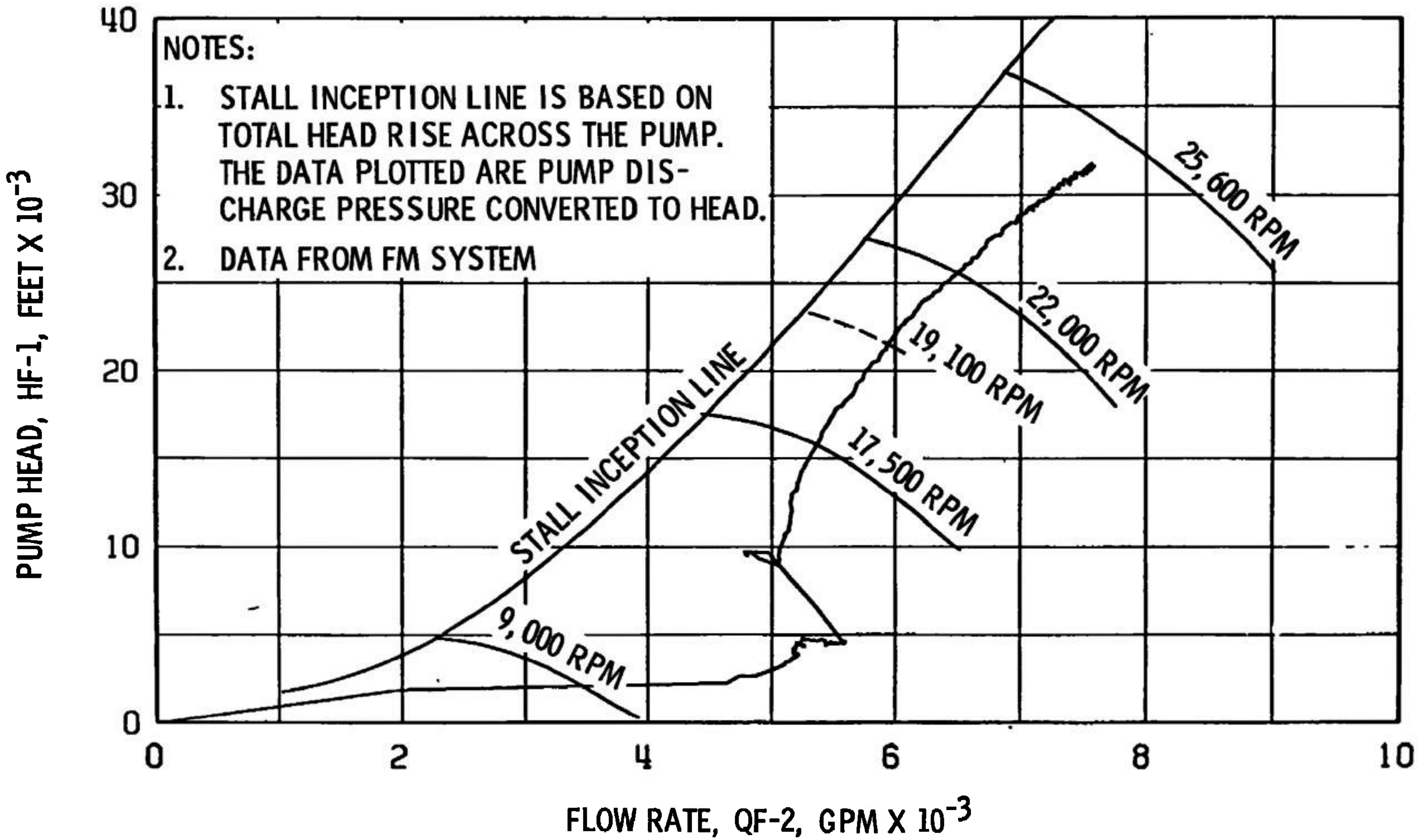
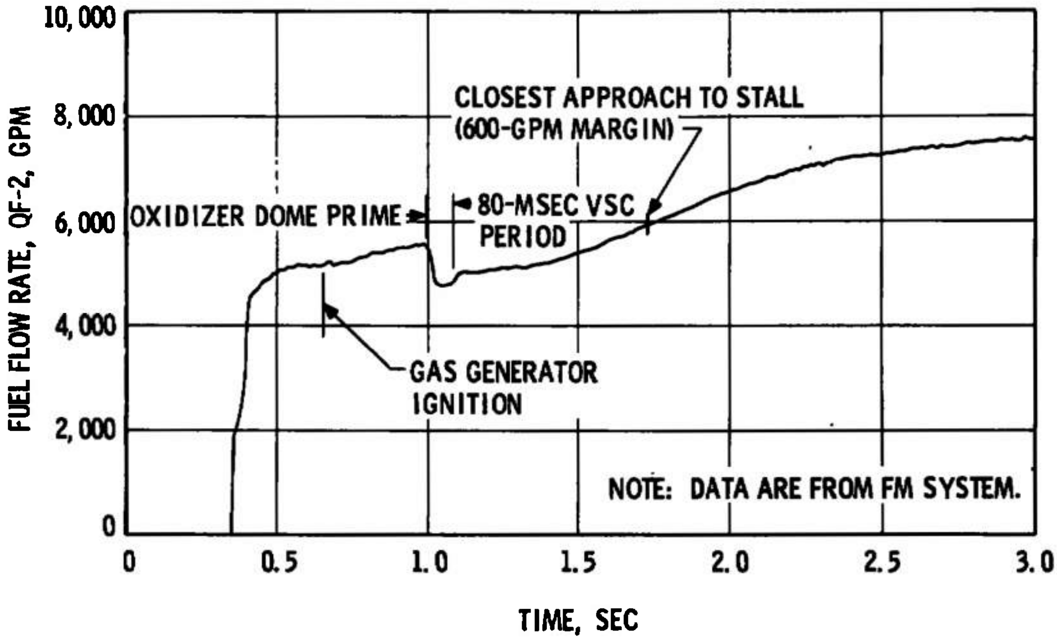


Fig. 22 Augmented Spark Igniter Ignition Detect Time Comparison

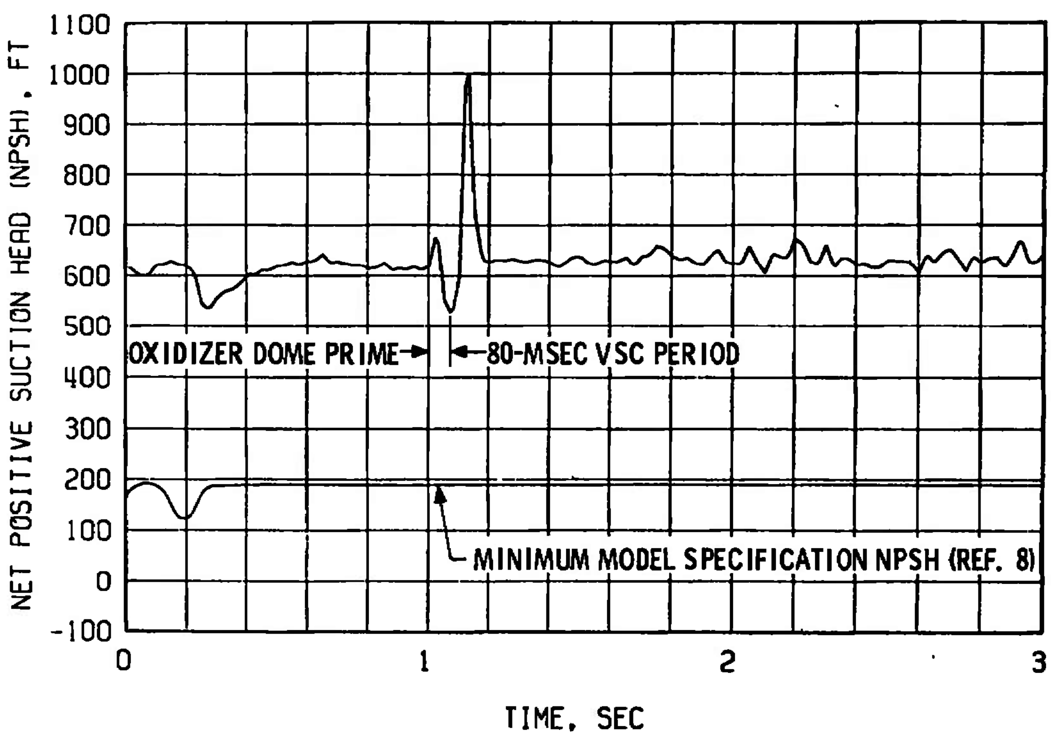


a. Fuel Pump Discharge Head-Flow Transient, Start

Fig. 23 Fuel Pump Start Transient Performance, Firing 20C

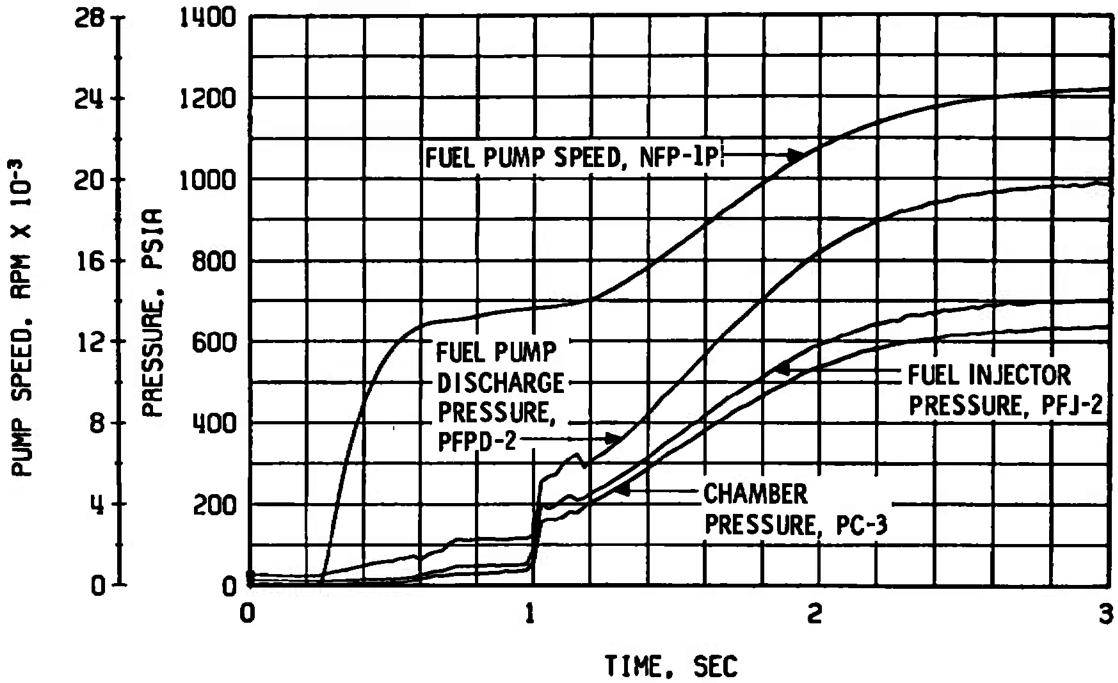


b. Fuel Pump Discharge Flow Transient, Start

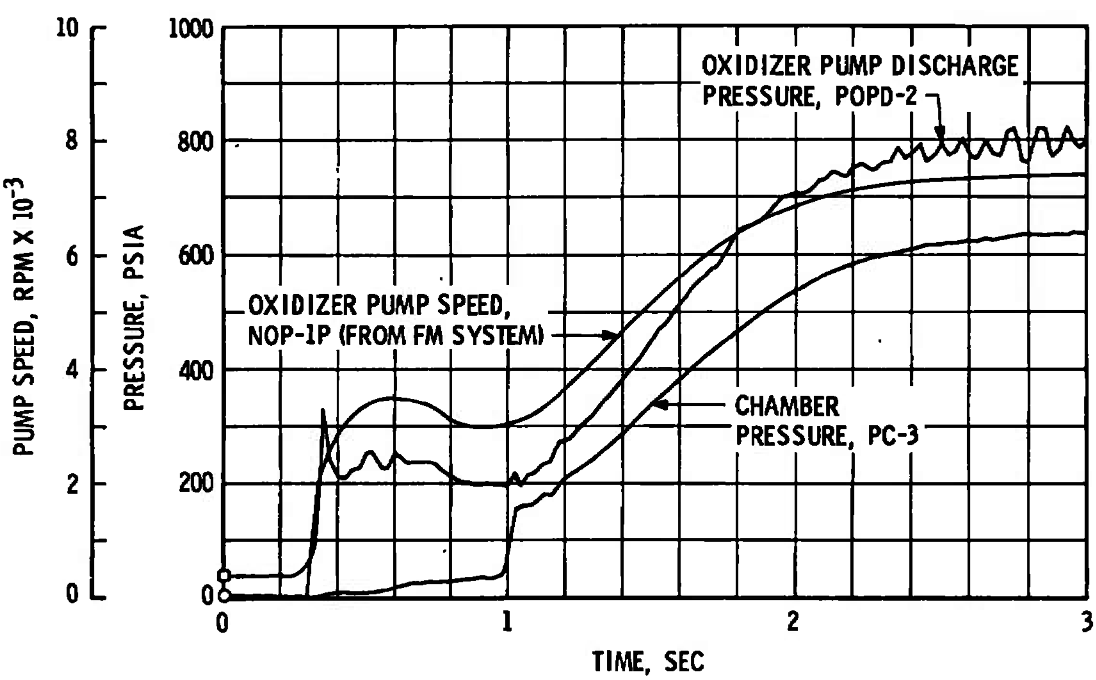


c. Fuel Pump NPSH during Start Transient

Fig. 23 Concluded

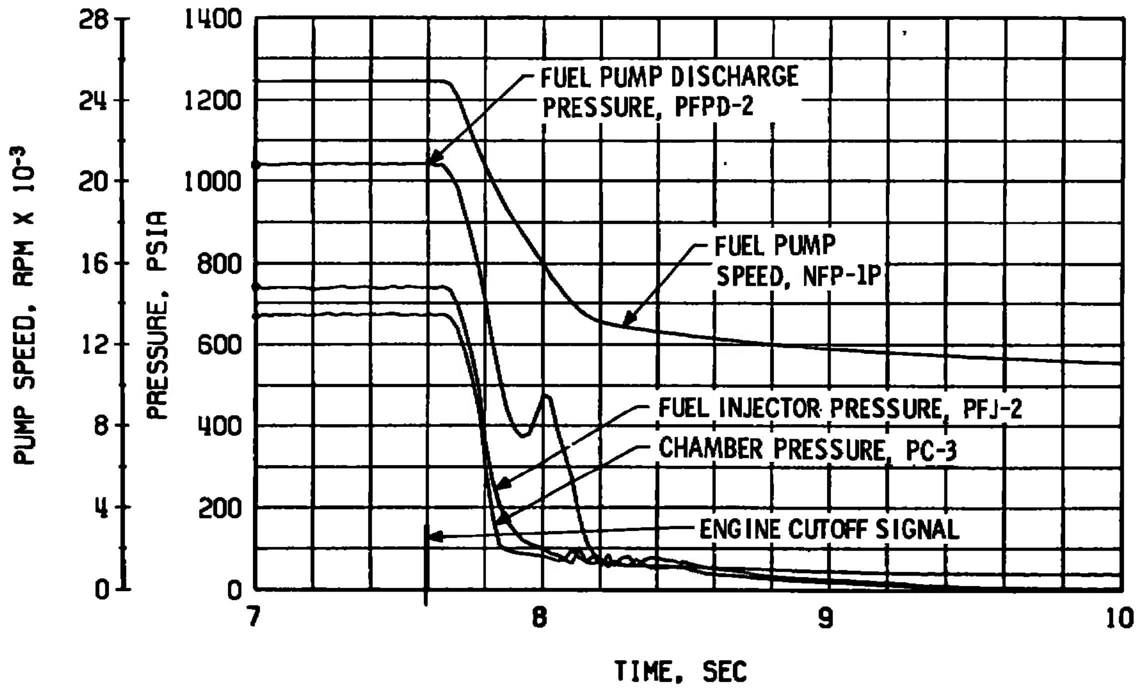


a. Thrust Chamber Fuel System, Start

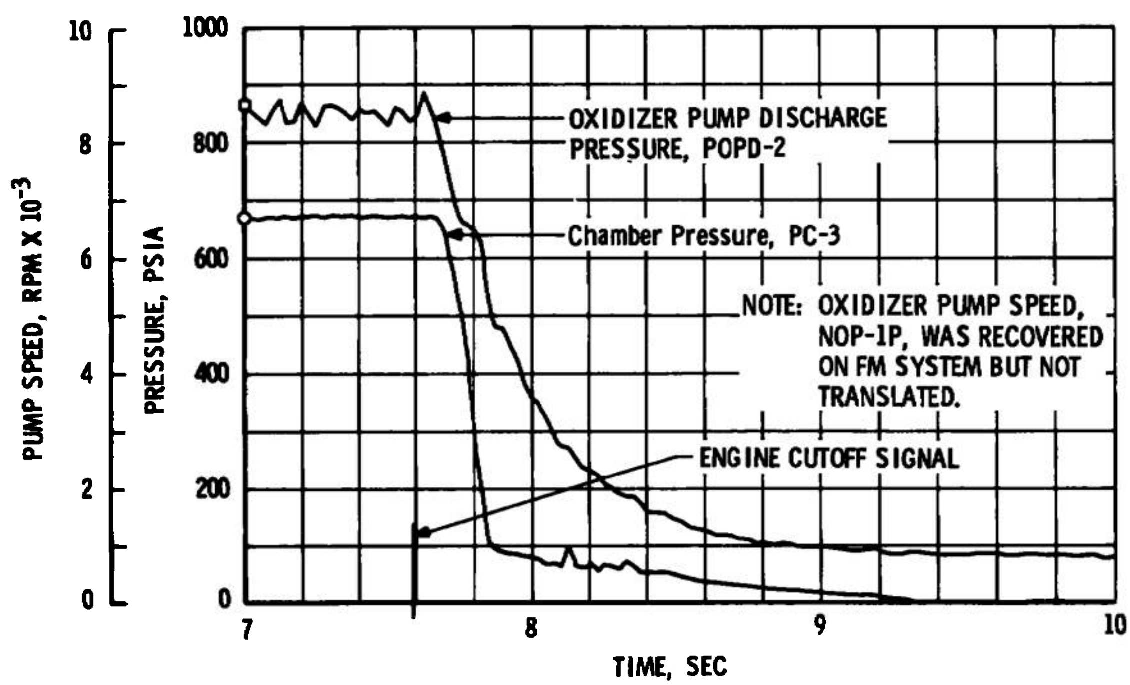


b. Thrust Chamber Oxidizer System, Start

Fig. 24 Engine Transient Operation, Firing 20D

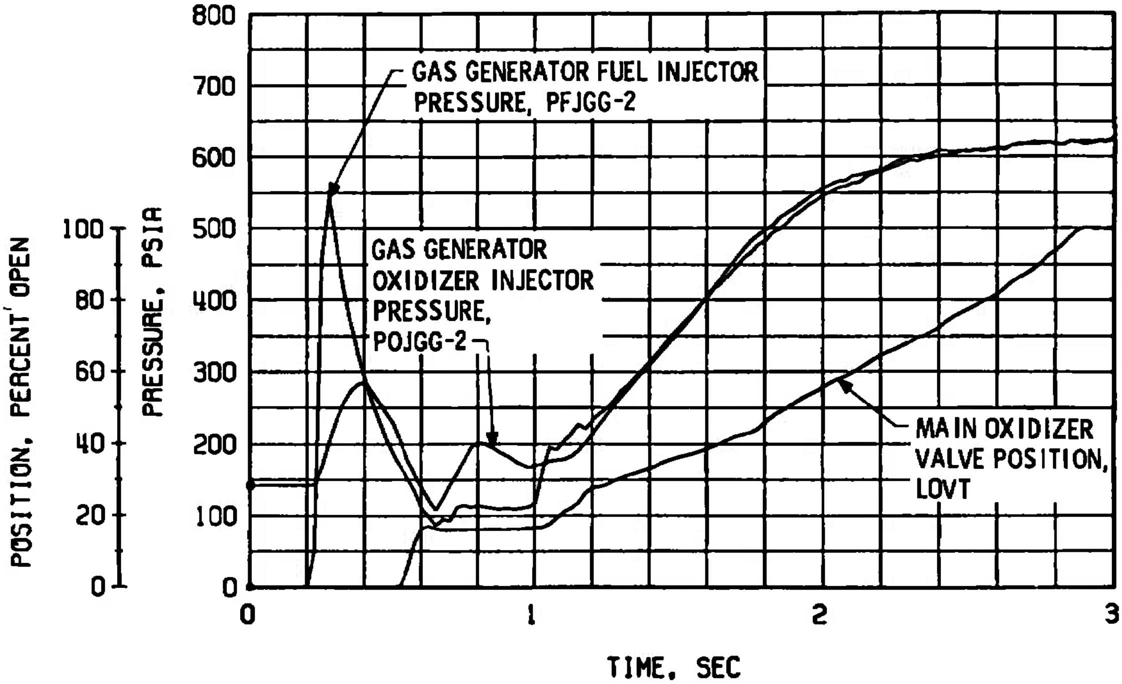


c. Thrust Chamber Fuel System, Shutdown

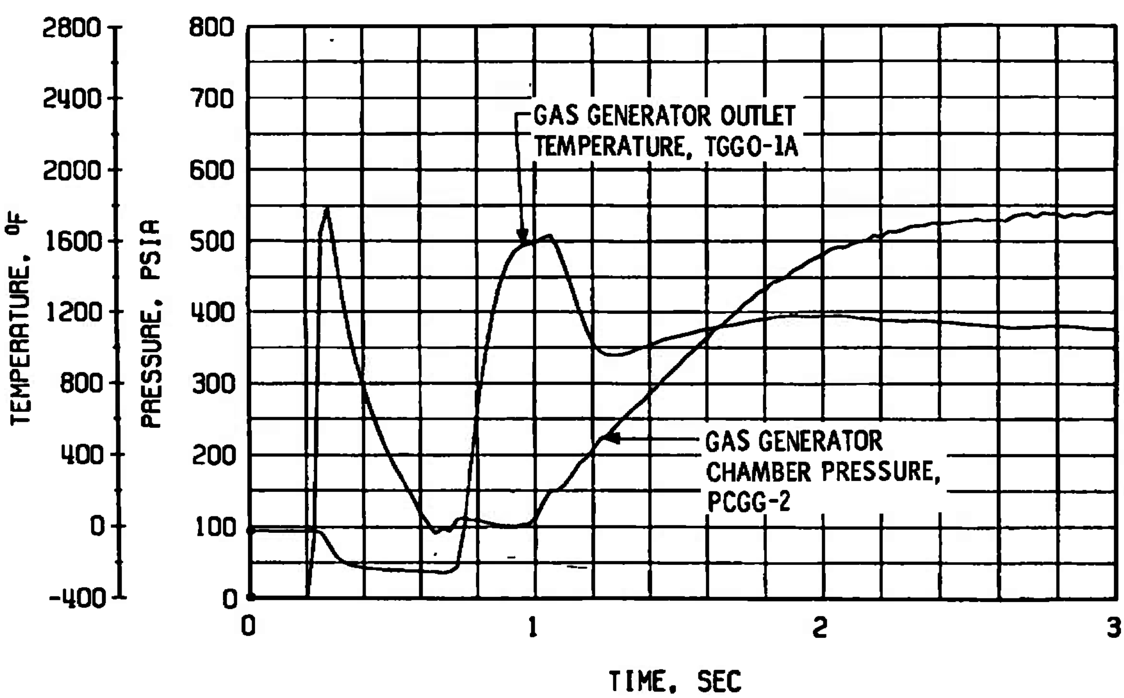


d. Thrust Chamber Oxidizer System, Shutdown

Fig. 24 Continued

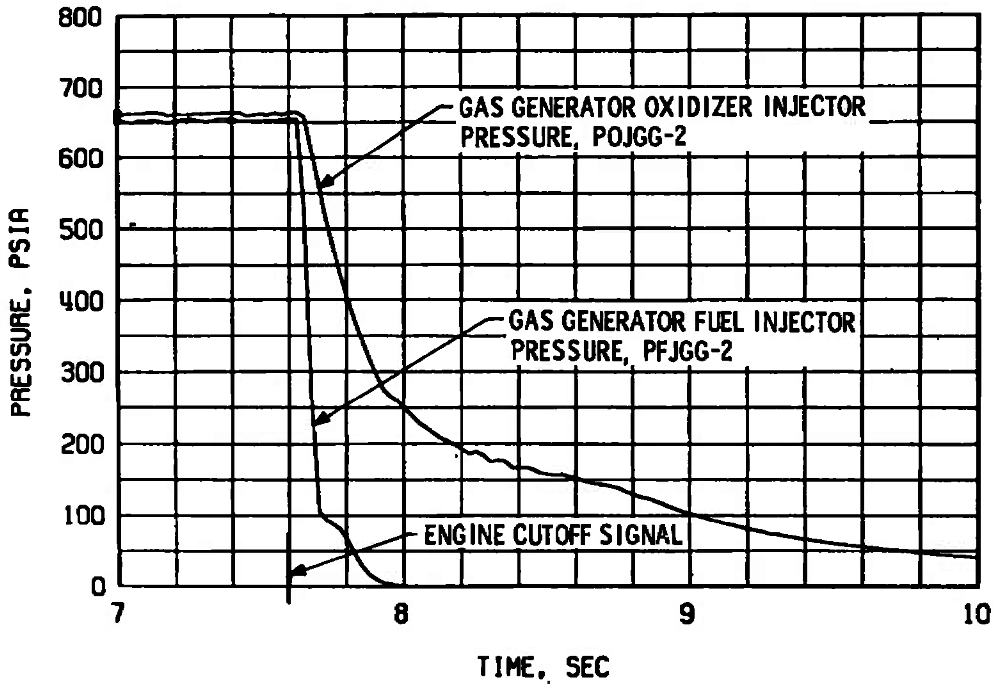


e. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

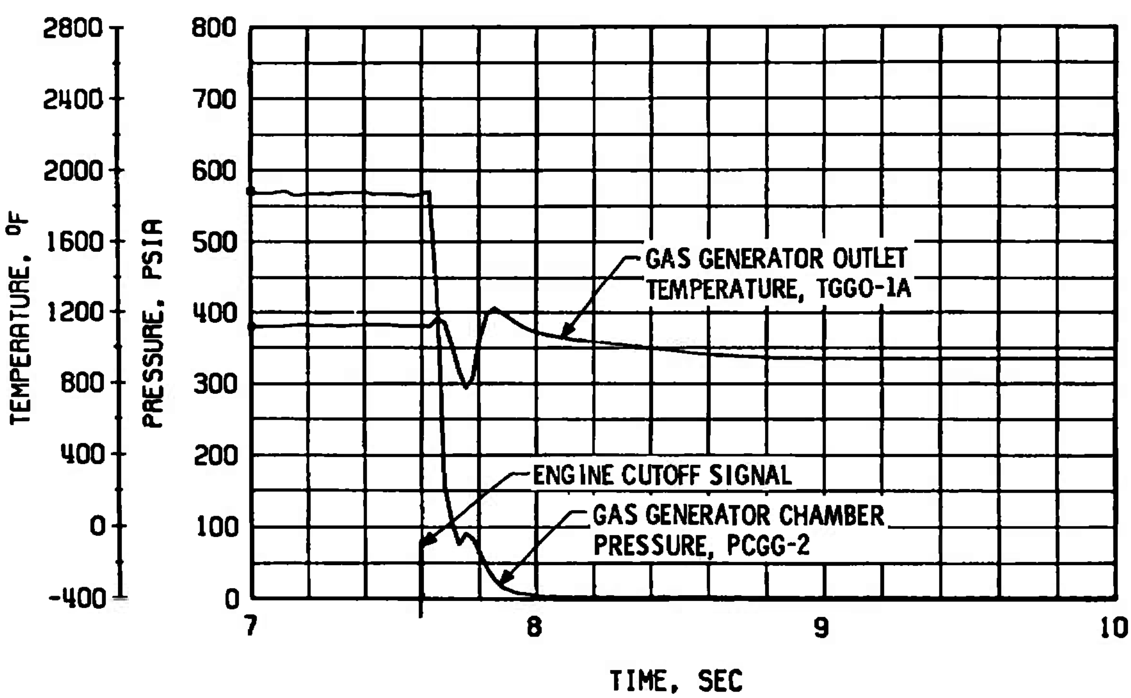


f. Gas Generator Chamber Pressure and Temperature, Start

Fig. 24 Continued



g. Gas Generator Injector Pressures, Shutdown



h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 24 Concluded

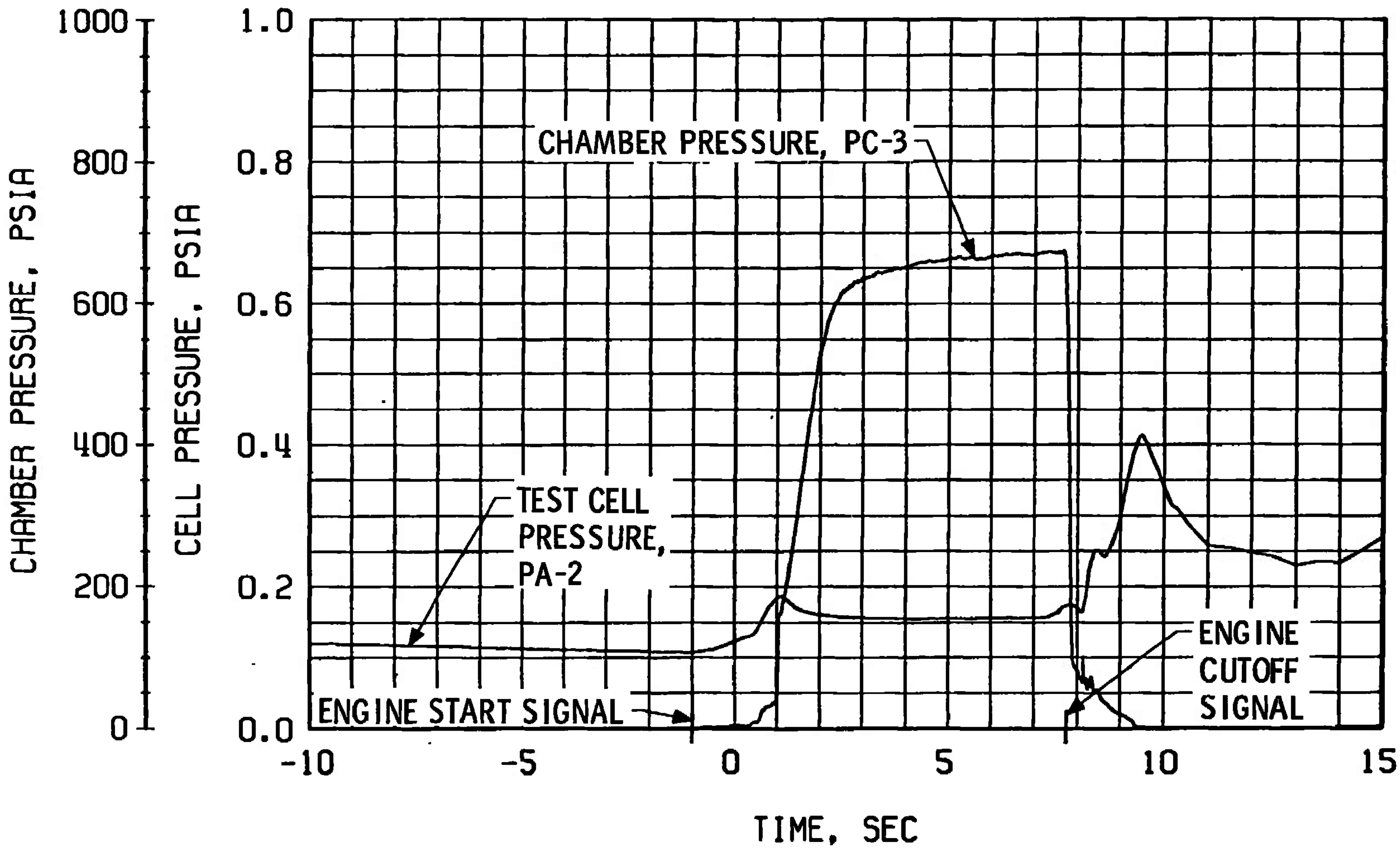
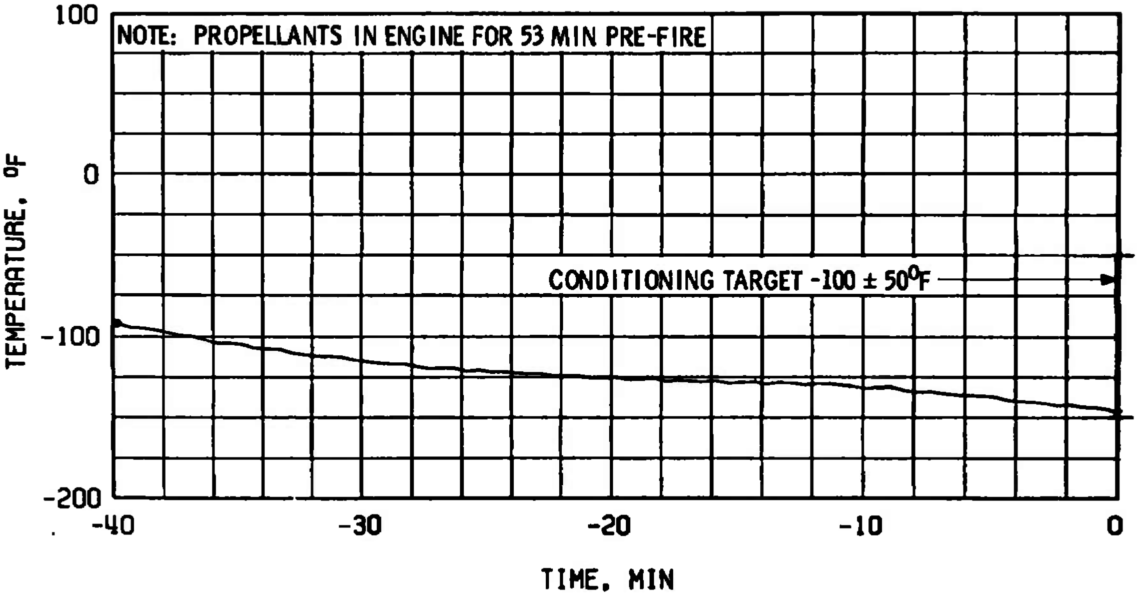
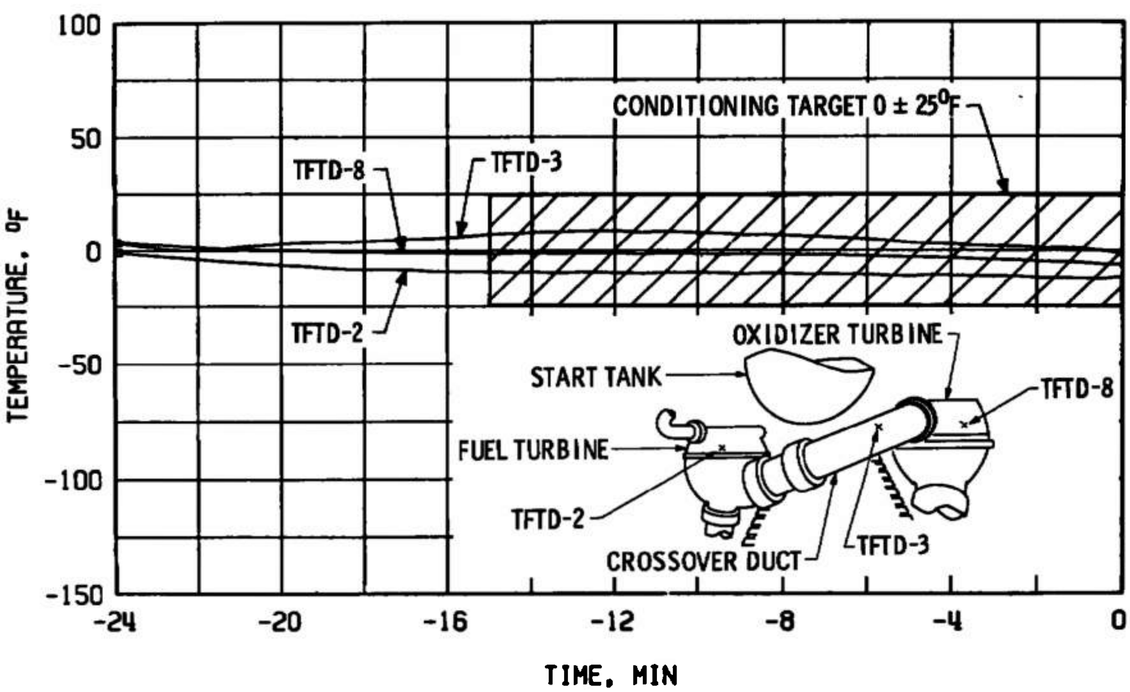


Fig. 25 Engine Ambient and Combustion Chamber Pressures, Firing 20D

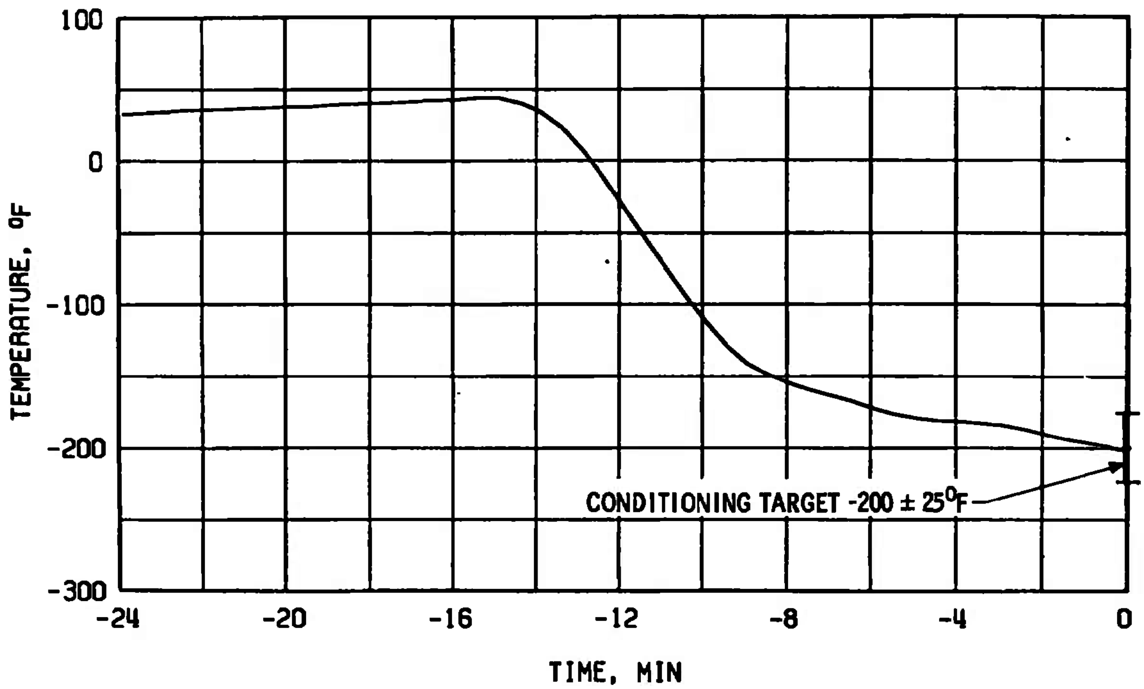


a. Main Oxidizer Valve Second-Stage Actuator

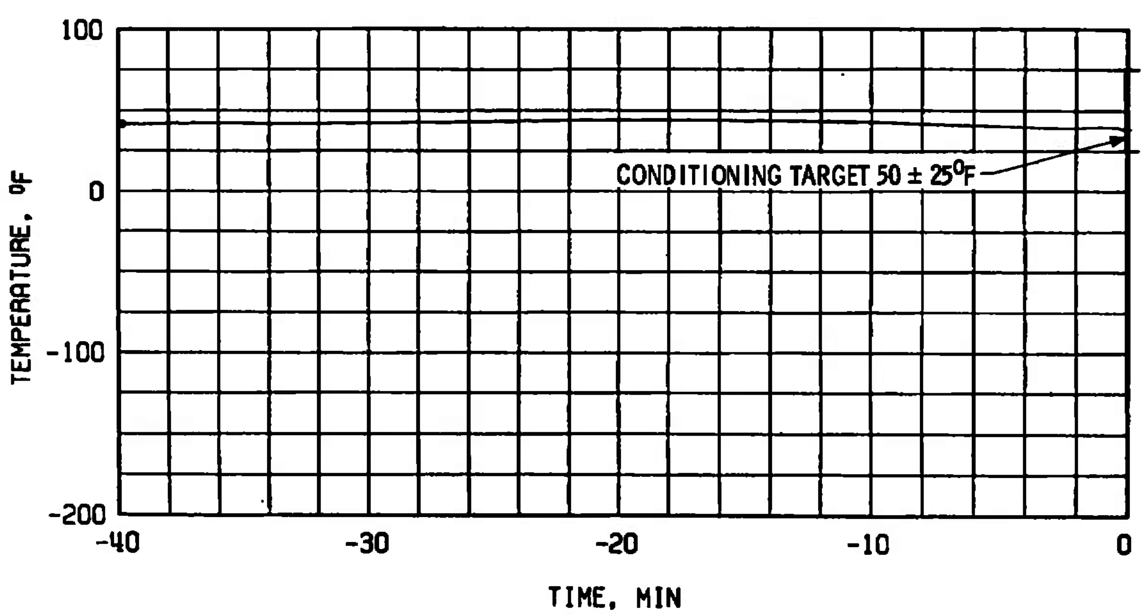


b. Crossover Duct, TFTD

Fig. 26 Thermal Conditioning History of Engine Components, Firing 20D

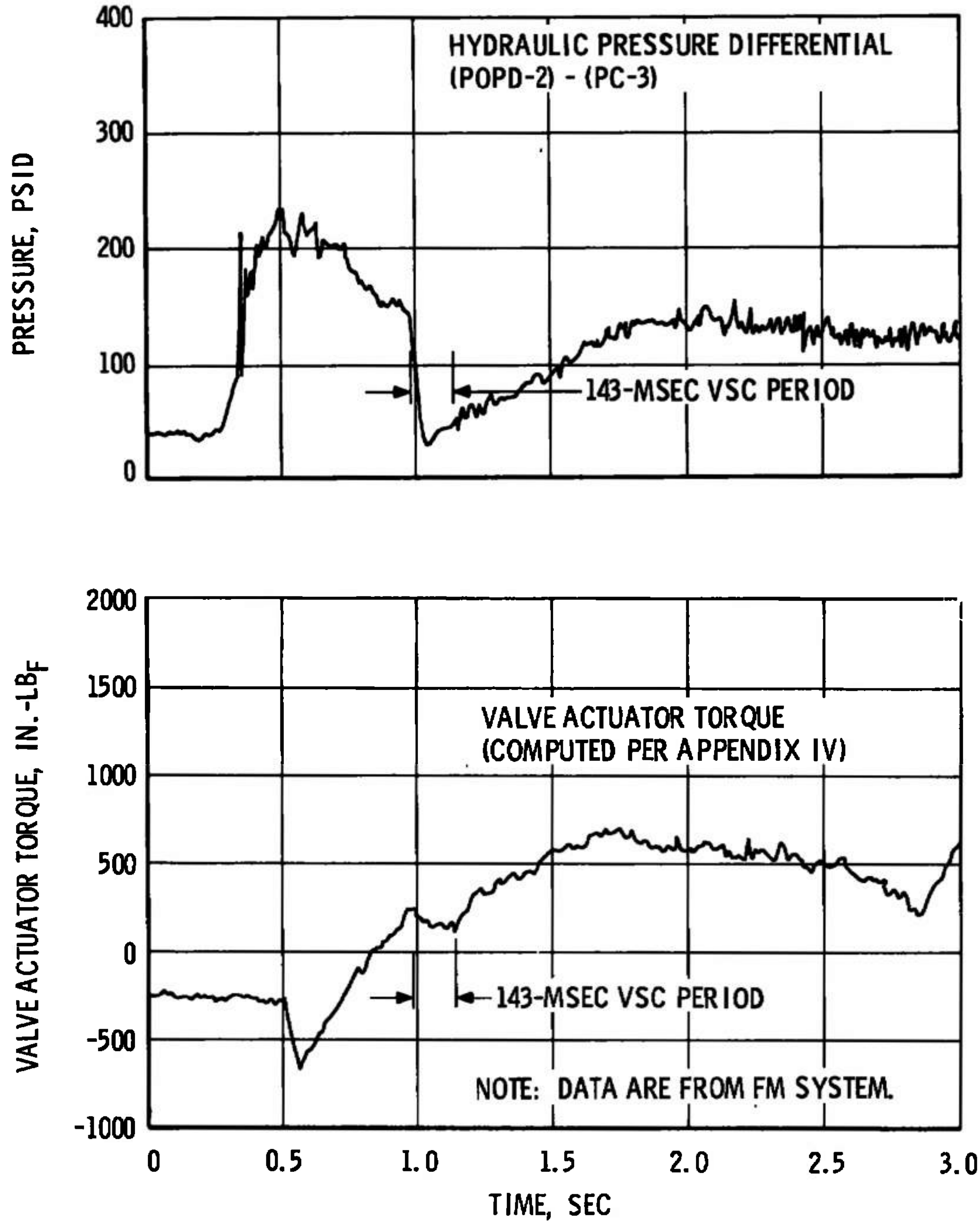


c. Thrust Chamber Throat, TTC-1P



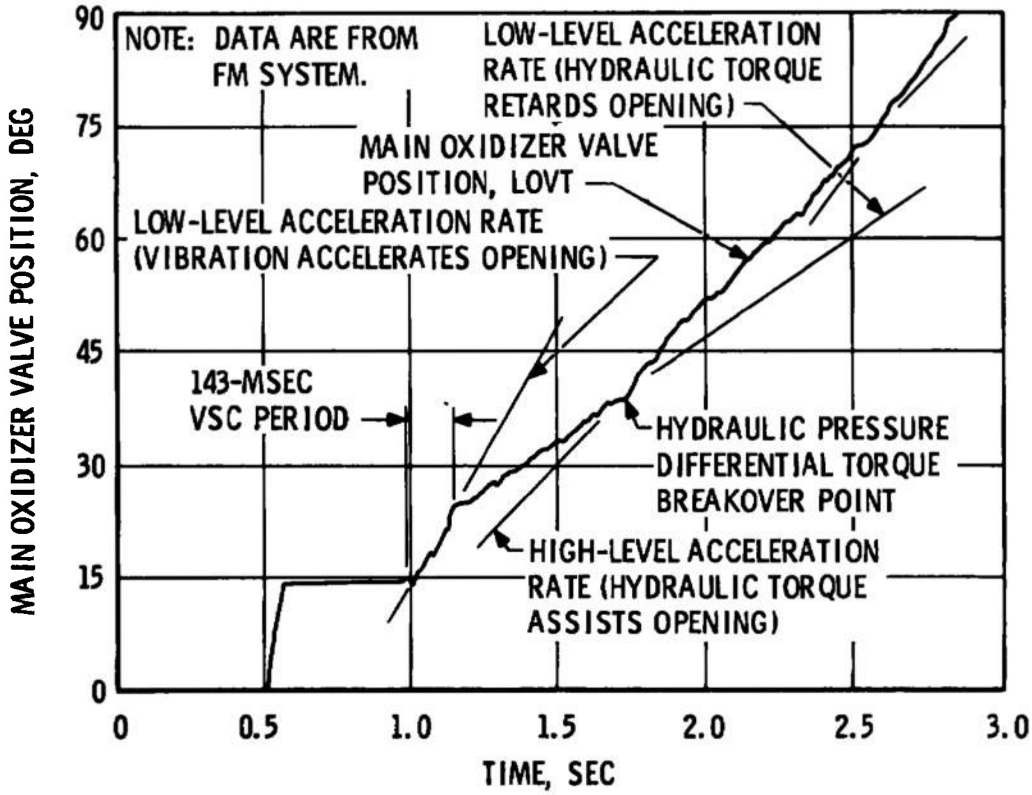
d. Start Tank Discharge Valve, TSTDVOC

Fig. 26 Concluded

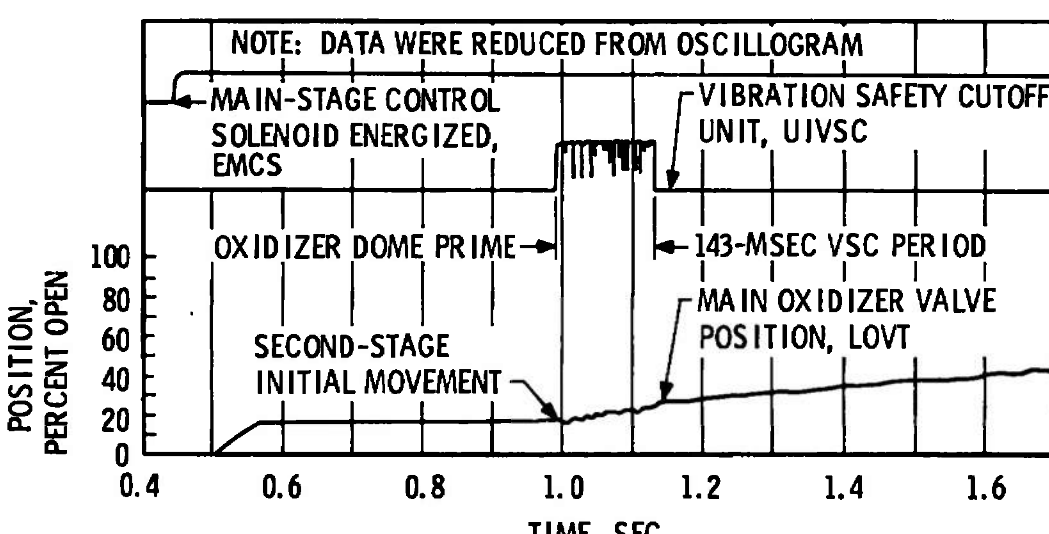


a. Main Oxidizer Valve Torque during Opening

Fig. 27 Main Oxidizer Valve Opening Characteristics, Firing 20D

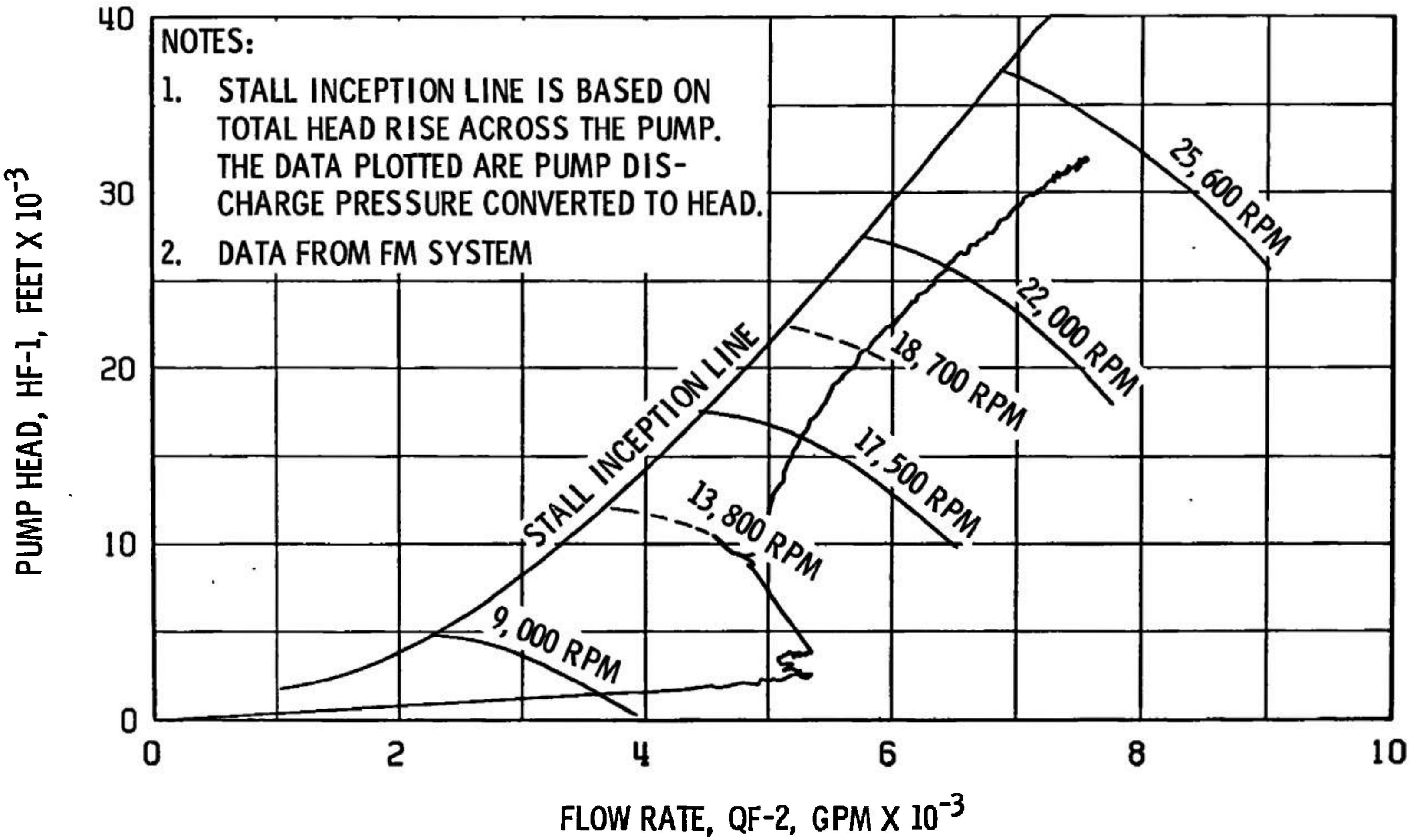


b. Main Oxidizer Valve Opening Time History



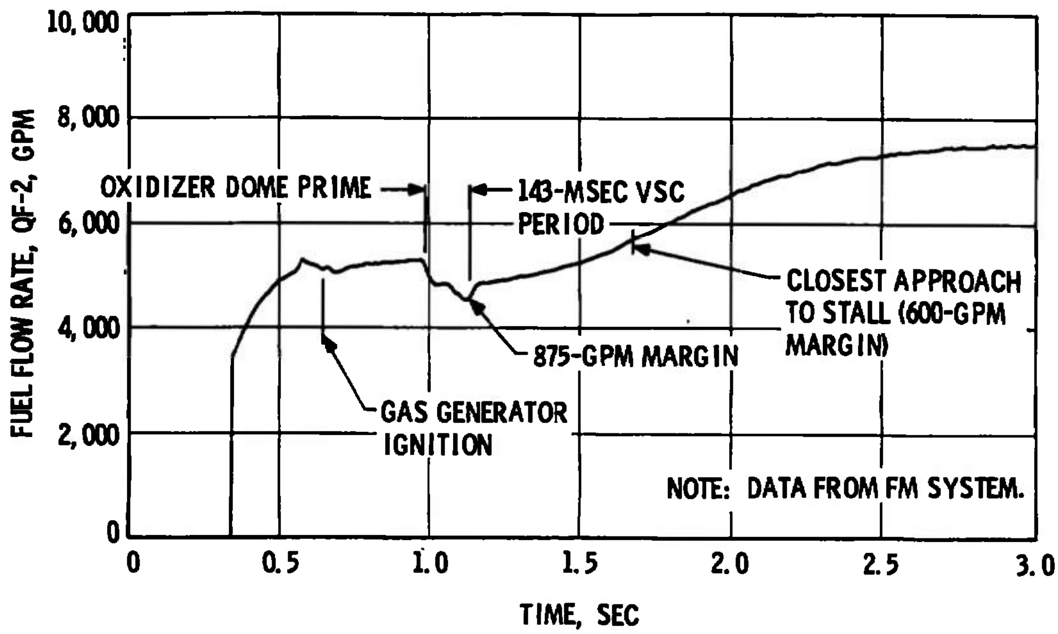
c. Engine Vibration and Main Oxidizer Valve Opening

Fig. 27 Concluded

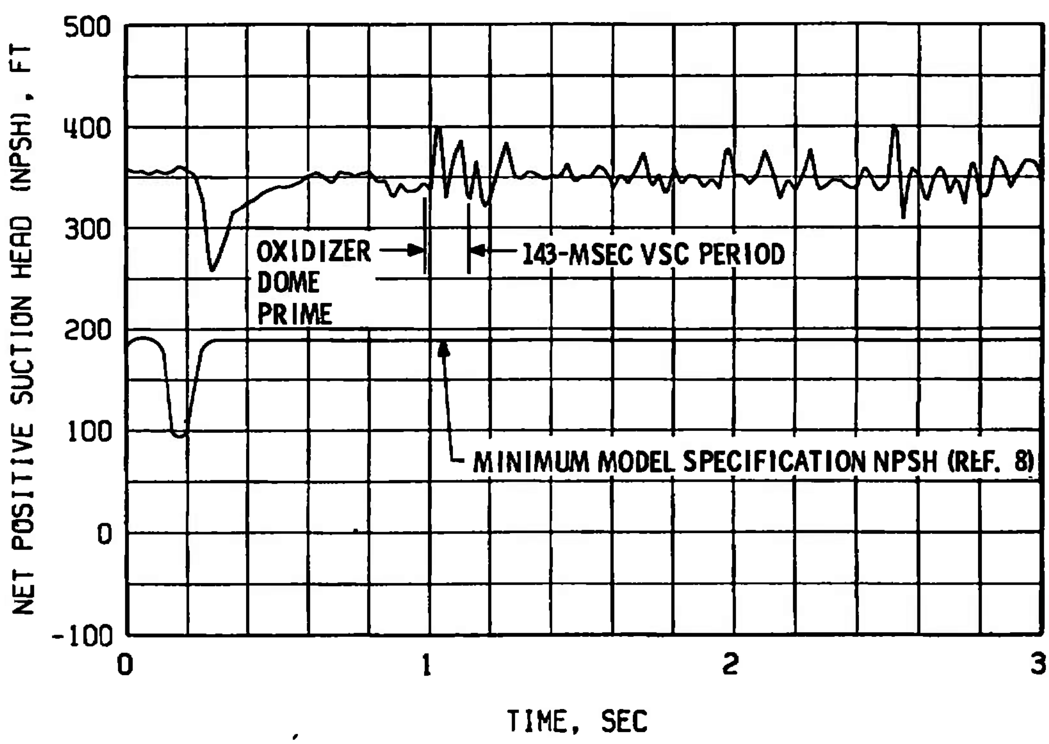


a. Fuel Pump Discharge Head-Flow Transient, Start

Fig. 28 Fuel Pump Start Transient Performance, Firing 20D

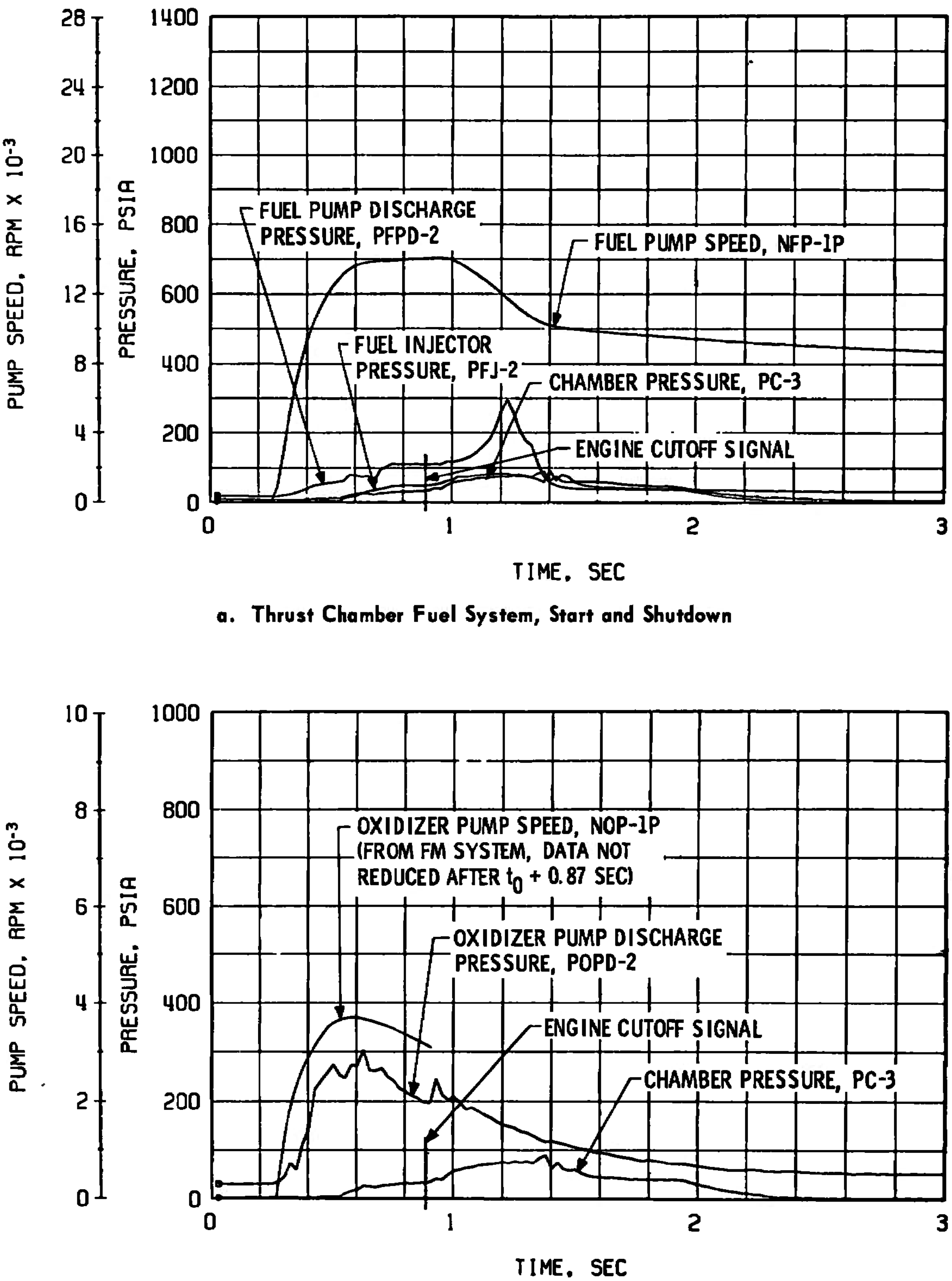


b. Fuel Pump Discharge Flow Transient, Start



c. Fuel Pump NPSH during Start Transient

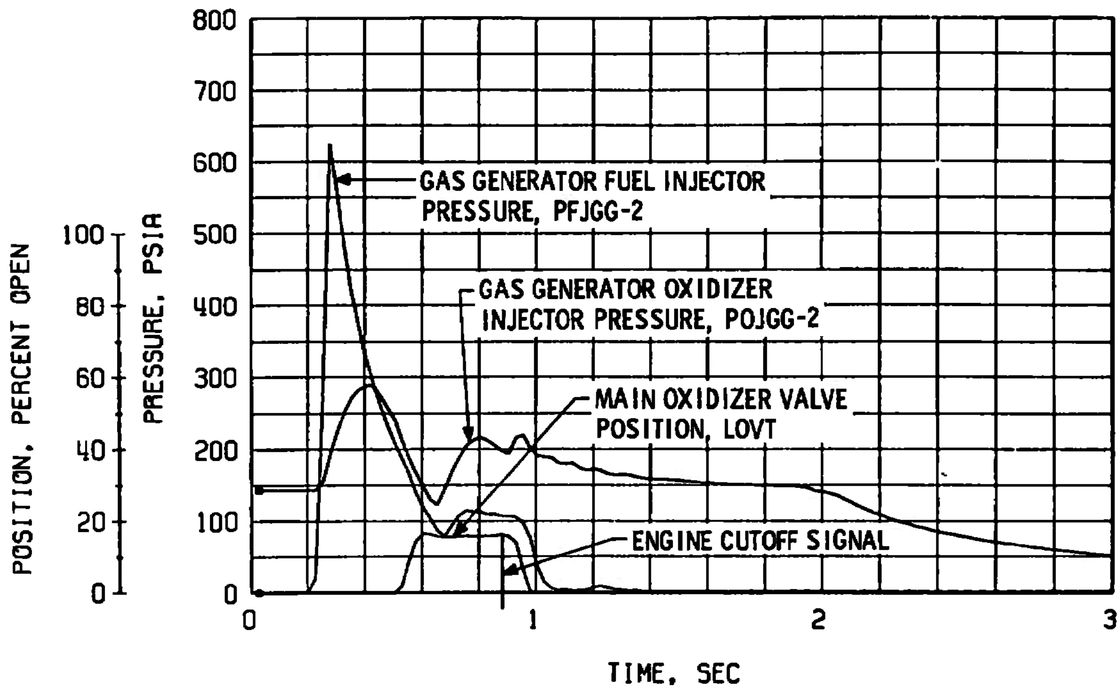
Fig. 28 Concluded



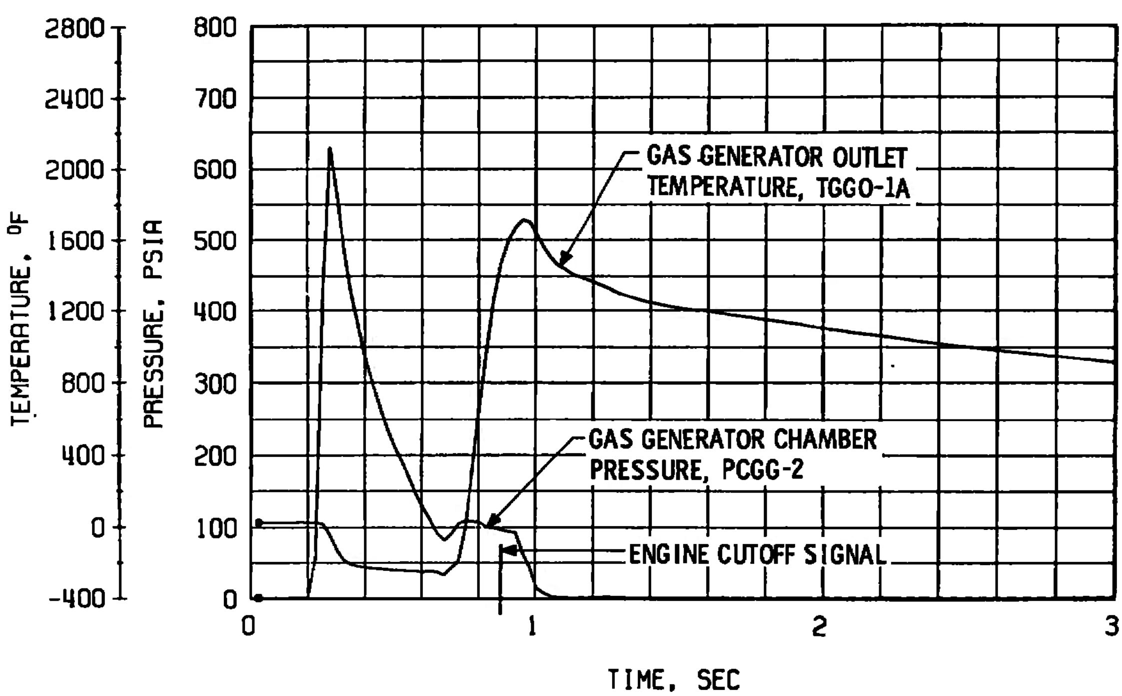
a. Thrust Chamber Fuel System, Start and Shutdown

b. Thrust Chamber Oxidizer System, Start and Shutdown

Fig. 29 Engine Transient Operation, Firing 20E



c. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start and Shutdown



d. Gas Generator Chamber Pressure and Temperature, Start and Shutdown

Fig. 29 Concluded

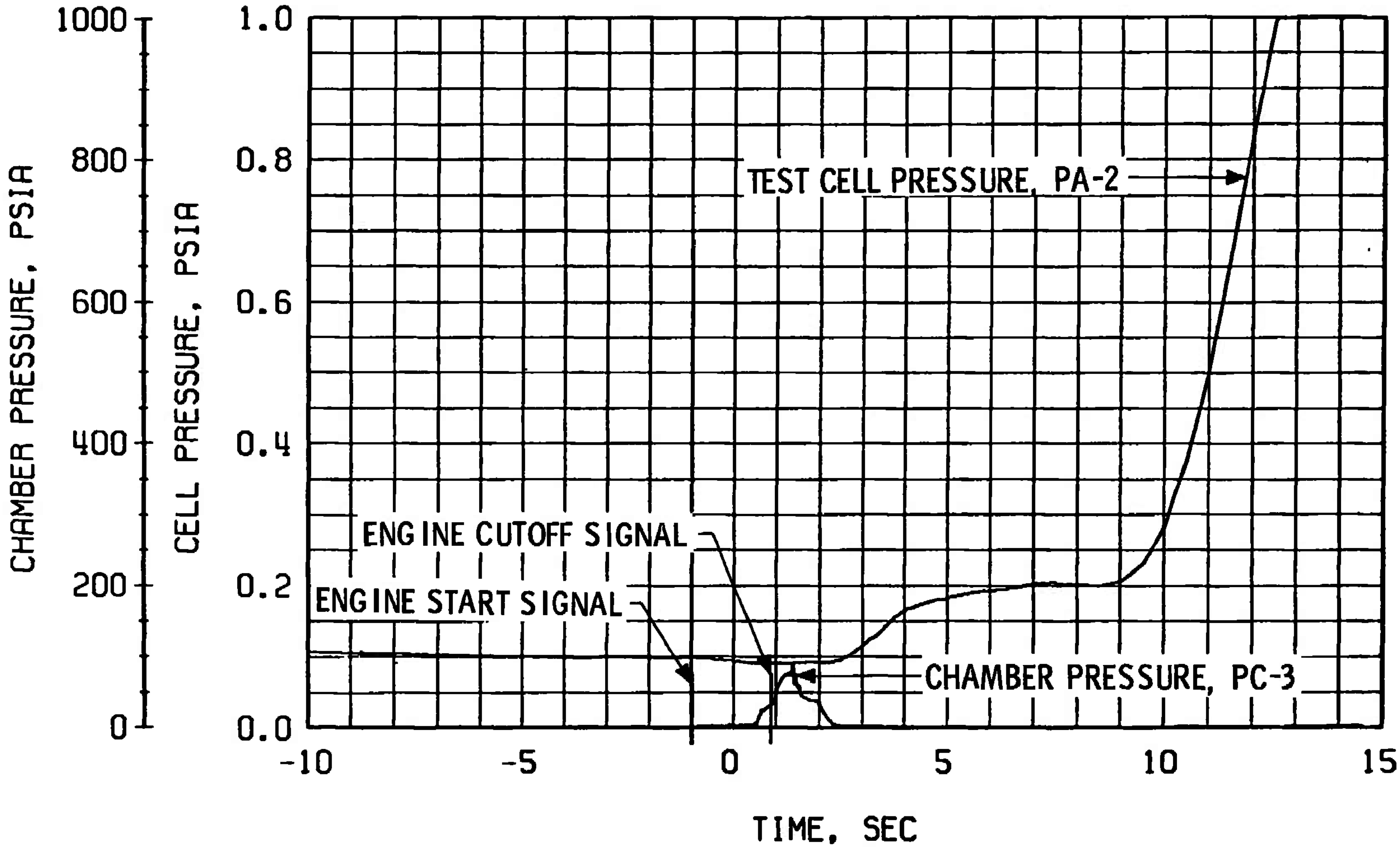
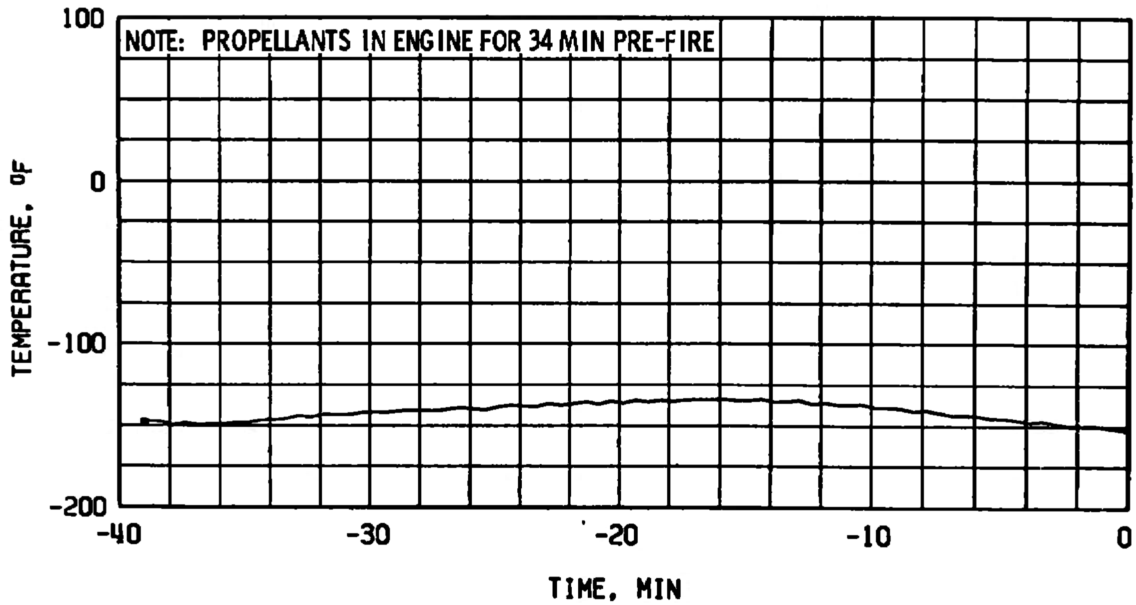
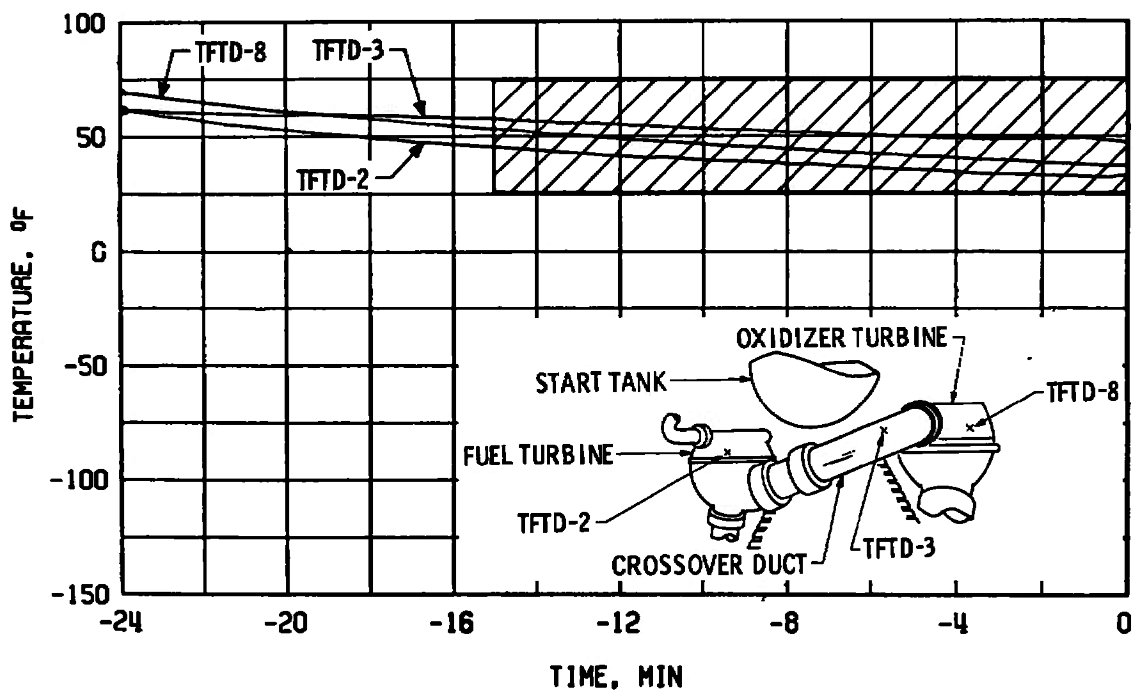


Fig. 30 Engine Ambient and Combustion Chamber Pressures, Firing 20E

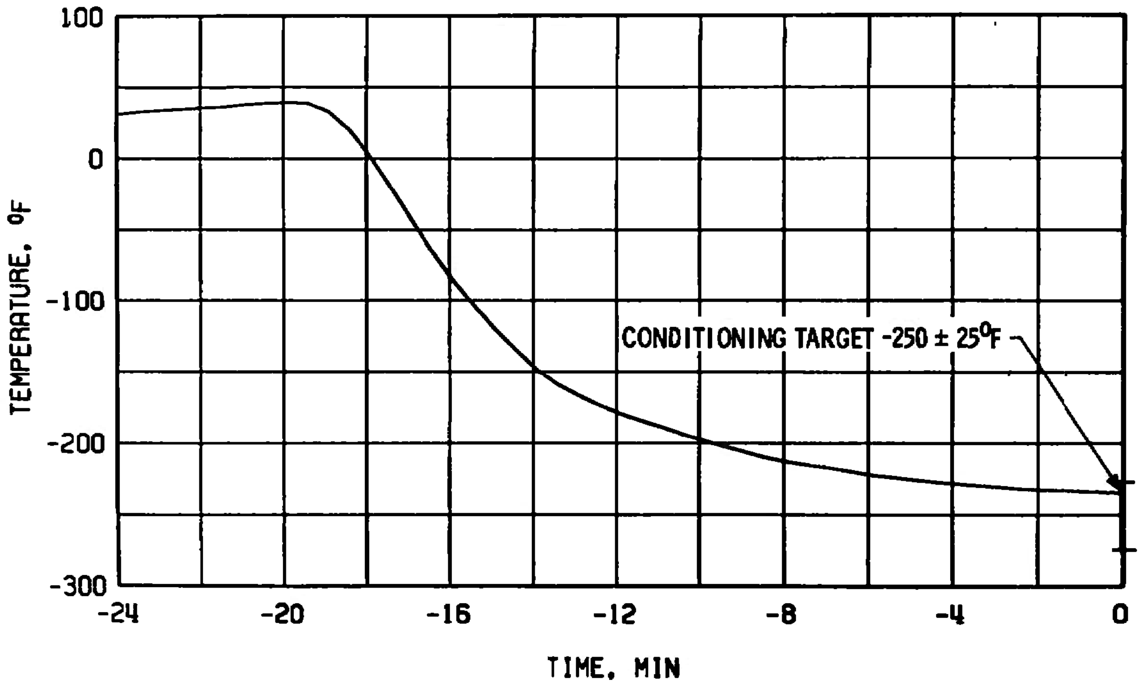


a. Main Oxidizer Valve Second-Stage Actuator

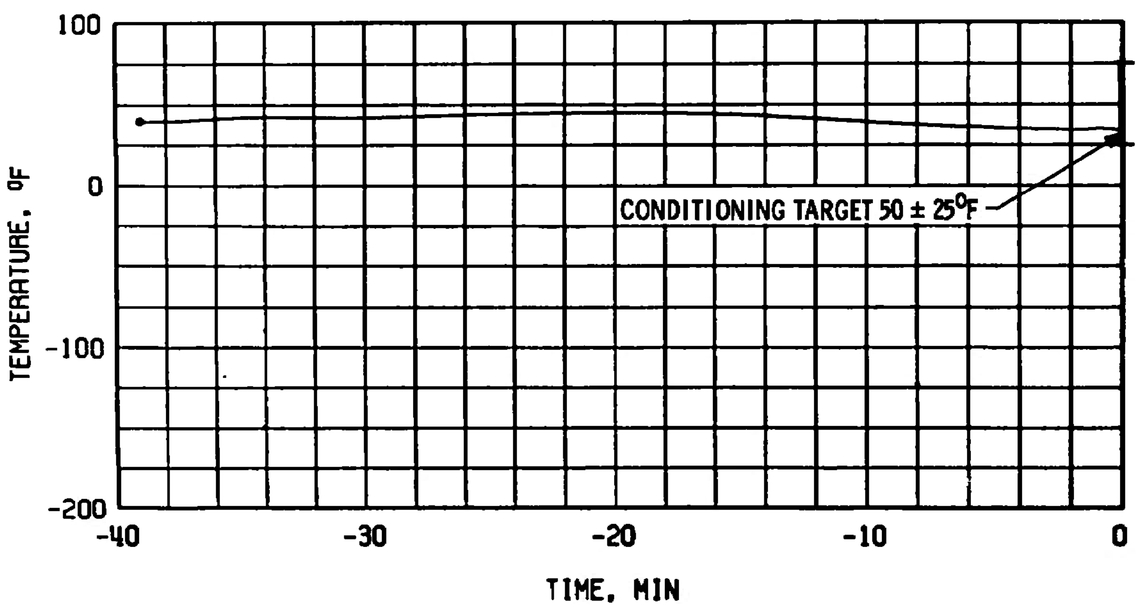


b. Crossover Duct, TFTD

Fig. 31 Thermal Conditioning History of Engine Components, Firing 20E

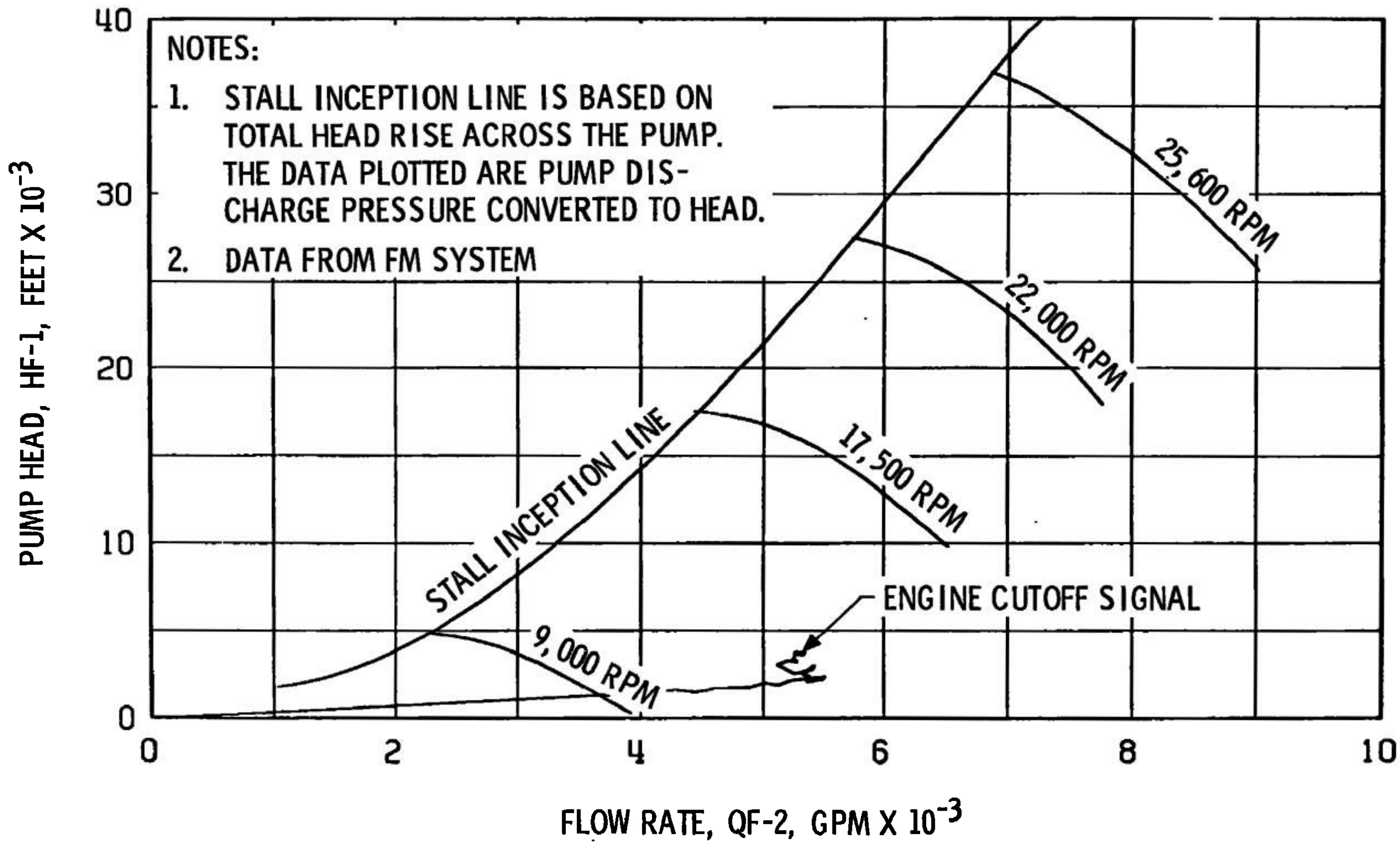


c. Thrust Chamber Throat, TTC-1P



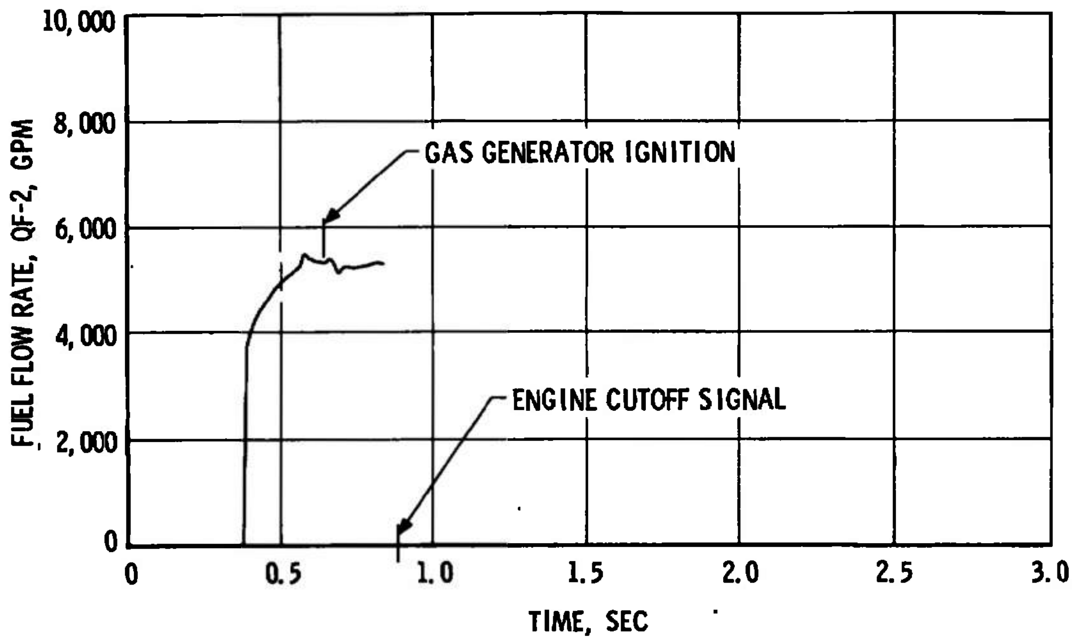
d. Start Tank Discharge Valve, TSTDVOC

Fig. 31 Concluded

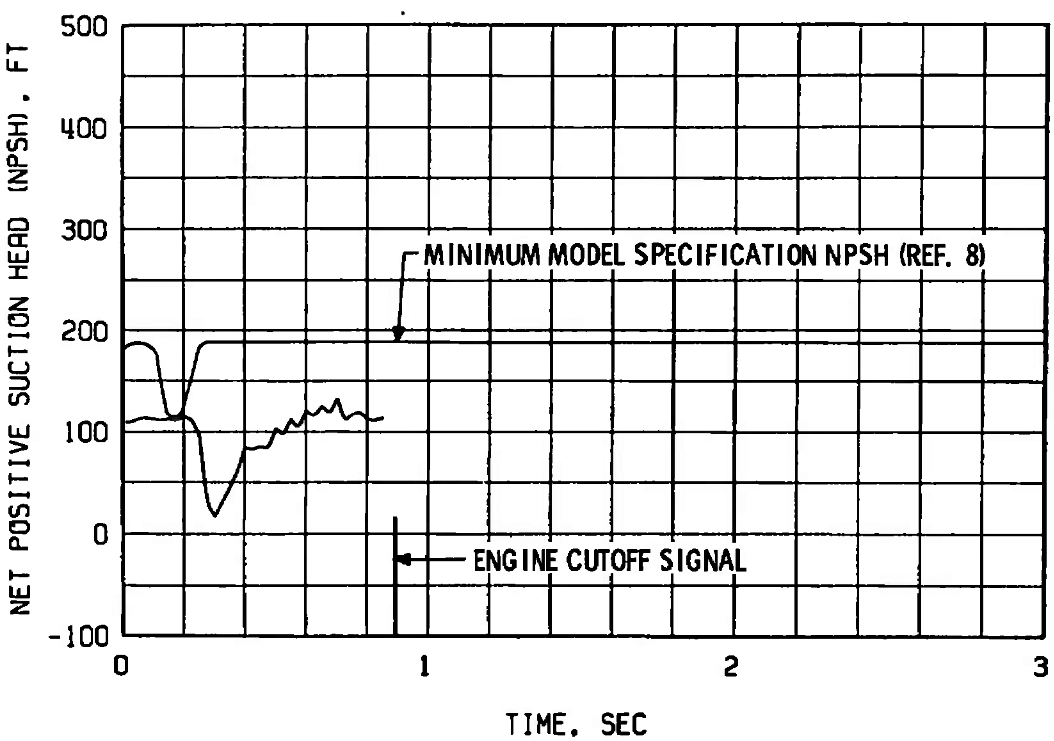


a. Fuel Pump Discharge Head-Flow Transient, Start

Fig. 32 Fuel Pump Start Transient Performance, Firing 20E



b. Fuel Pump Discharge Flow Transient, Start



c. Fuel Pump NPSH during Start Transient

Fig. 32 Concluded

TABLE I
MAJOR ENGINE COMPONENTS

Part Name	P/N	S/N
Thrust Chamber Body	206600-31	4072755
Thrust Chamber Injector Assembly	208021-11	4071421
Fuel Turbopump Assembly	459000-171	4078258
Oxidizer Turbopump Assembly	458175-81	6645876
Start Tank	303439	0038
Augmented Spark Igniter	206280-81	4078806
Gas Generator Fuel Injector and Combustor	308360-11	2008734
Gas Generator Oxidizer Injector and Poppet Assembly	303323	4076827
Helium Regulator Assembly	556948	4072709
Electrical Control Package	502670-11	4078604
Primary Flight Instrumentation Package	703685	4077391
Auxiliary Flight Instrumentation Package	703680	4077313
Main Fuel Valve	409120	4062472
Main Oxidizer Valve	409973	4077271
Gas Generator Control Valve	309040	4076768
Start Tank Discharge Valve	306875	4081218
Oxidizer Turbine Bypass Valve	409930	4093026
Propellant Utilization Valve	251351-11	4068732
Main-Stage Control Valve	555767	8284307
Ignition Phase Control Valve	555767	8284305
Helium Control Valve	NA5-27273	340919
Start Tank Vent and Relief Valve	557818	4062234
Helium Tank Vent Valve	NA5-27273	340918
Fuel Bleed Valve	309034	4077233
Oxidizer Bleed Valve	309029	4076750
Augmented Spark Igniter Oxidizer Valve	308880	4089946
Pressure-Actuated Purge Control Valve	557823	4075865
Pressure-Actuated Shutdown Valve Assembly	557817	4067200
Start Tank Fill/Refill Valve	558000	4072899
Fuel Flowmeter	251225	4076564
Oxidizer Flowmeter	251216	4077137
Fuel Injector Temperature Transducer	NA5-27441	12350
Restartable Ignition Detect Probe	NA5-27298T2	329

TABLE II
SUMMARY OF ENGINE ORIFICES

Orifice Name	Part Number	Diameter, in.	Date Effective	Comments
Gas Generator Fuel Supply Line	RD251-4107	0.468	---	1
Gas Generator Oxidizer Supply Line	RD251-4106	0.268	---	1
Oxidizer Turbine Bypass Valve Nozzle	RD273-8002	1.430	November 17, 1967	None
Oxidizer Turbine Exhaust Manifold	RD251-9004	10.00	---	1
Main Oxidizer Valve Closing Control Line	556443-0275	0.0275	December 9, 1967	None
Augmented Spark Igniter Oxidizer Supply Line	406361	0.150	October 20, 1967	None

[1]Installed before Engine Delivery to AEDC

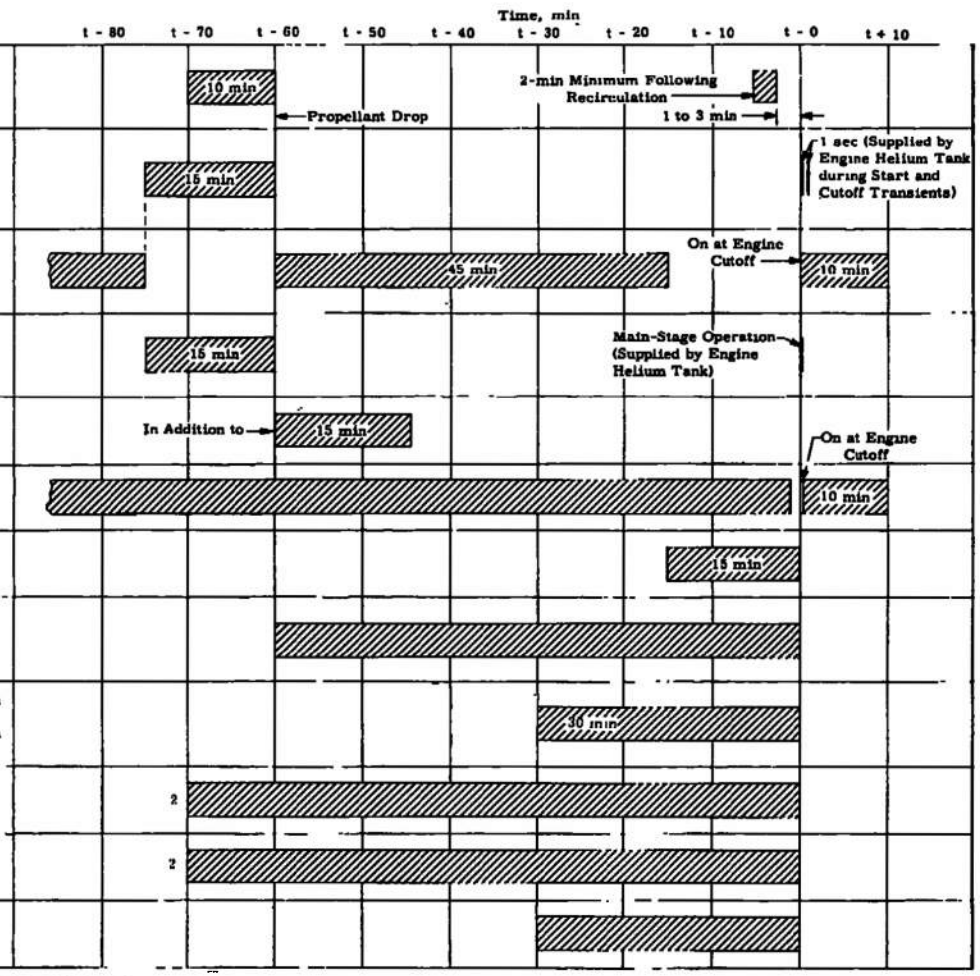
TABLE III
ENGINE MODIFICATIONS
(BETWEEN TESTS J4-1801-19 AND J4-1801-20)

Modification Number	Completion Date	Description of Modification
RFD[1]-41-1-67	December 9, 1967	Reorificing of main oxidizer valve to 1350^{+10}_{-20} msec second-stage ramp time.
RFD-82-67	December 12, 1967	(1) Provide additional helium purge to fuel turbine seal - set to indicate 30 psia on fuel turbine seal purge line - to be turned on at cutoff for 30 min after each firing. (2) Install thermocouple on turbine seal drain line.

[1]RFD - Rocketdyne Field Directive

TABLE IV
ENGINE PURGE AND COMPONENT CONDITIONING SEQUENCE

Turbopump[1] and Gas Generator Purge (Purge Manifold System)	Helium, 82 - 125 psia; 50 - 200°F; (Nominal) 6 scfm at Customer Connect
Oxidizer Dome and Gas Generator Liquid Oxygen Injector (Engine Pneumatic System)	Nitrogen, 400 ± 25 psig; 50 - 200°F; (Minimum) 230 scfm
Oxidizer Dome (Facility Line to Port COA3)	Nitrogen; 400 - 450 psig; 100 - 200°F; (Nominal) 200 scfm
Oxidizer Turbopump Intermediate Seal Cavity (Engine Pneumatic System)	Helium, 400 ± 25 psig; Ambient Temperature; 2600 - 7000 scfm
Thrust Chamber Jacket (Customer Connect) Panel	Helium, 40 - 60 psig; 50 - 200°F; (Nominal) 60 scfm
	Helium; 12 - 14 psig; 50 - 200°F; (Nominal) 10 scfm
Thrust Chamber Temperature Conditioning	Helium, 1000 psig; -300°F to Ambient; 10 - 20 lb_m/min
Pump Inlet Pressure and Temperature Conditioning	Oxidizer, 35 to 48 psia; -298 to -280°F; Fuel, 28 to 46 psia; -424 to -416°F
Hydrogen Start Tank and Helium Tank Pressure and Temperature Conditioning	Hydrogen; 1200 to 1400 psia; -300 to -140°F; Helium, 1700 to 3250 psia; -300 to -140°F
Crossover Duct Temperature Conditioning	Helium; -300°F to Ambient
Main Oxidizer Valve Actuator Temperature Conditioning	Helium; -300°F to Ambient
Start Tank Discharge Valve Conditioning	Helium, Ambient Temperature



[1]Additional helium purge to fuel turbine seal set to 30 psia on fuel turbine seal purge line - on at cutoff for 30 min after each firing.

[2]Conditioning temperature to be maintained for the last 30 min of pre-fire.

TABLE V
SUMMARY OF TEST REQUIREMENTS AND RESULTS

Firing Number, J4-1901-20		20A Target	20A Actual	20B Target	20B Actual	20C Target	20C Actual	20D Target	20D Actual	20E Target	20E Actual
Firing Date/Time of Day, hr		12-14-67	1059	12-14-67	1207	12-14-67	1307	12-14-67	1404	12-14-67	1452
Pressure Altitude at Engine Start, ft		---	104,000	---	110,000	---	111,000	---	110,000	---	112,000
Firing Duration, sec[1]		32.5	32.574	7.5	7.589	7.5	7.588	7.5	7.590	$0.85^{+0.03}_{-0.00}$	0.875
Fuel Pump Inlet Conditions at Engine Start	Pressure, psia	25.5^{+1}_{-0}	28.2	25.5^{+1}_{-0}	25.6	38.0^{+1}_{-0}	38.2	29.0 ± 1	29.3	21.5^{+1}_{-0}	21.7
	Temperature, °F	-421.4 ± 0.4	-421.1	-421.4 ± 0.4	-421.2	-421.4 ± 0.4	-421.4	-421.4 ± 0.4	-421.4	-421.4 ± 0.4	-421.3
Oxidizer Pump Inlet Conditions at Engine Start	Pressure, psia	33.0^{+1}_{-0}	33.8	33.0^{+1}_{-0}	33.8	33.0^{+1}_{-0}	33.6	37.0 ± 1	36.9	28.0 ± 1	28.2
	Temperature, °F	-294.5 ± 0.4	-294.5	-284.5 ± 0.4	-294.8	-294.5 ± 0.4	-294.8	-294.5 ± 0.4	-294.8	-295.0 ± 0.4	-295.0
Start Tank Conditions at Engine Start	Pressure, psia	1250 ± 10	1245	1200 ± 10	1198	1200 ± 10	1204	1250 ± 10	1249	1400 ± 10	1401
	Temperature, °F	-140 ± 10	-145	-200 ± 10	-205	-200 ± 10	-204	-250 ± 10	-249	-240 ± 10	-242
Helium Tank Conditions at Engine Start	Pressure, psia	---	2113	---	2171	---	2175	---	2180	---	2093
	Temperature, °F	---	-145	---	-204	---	-203	---	-246	---	-240
Thrust Chamber Temperature Conditions at Engine Start, °F	Throat	-250 ± 25	-223	-250 ± 25	-257	-150^{+20}_{-10}	-155	-200 ± 25	-200	-250 ± 25	-234
	Average	---	-250	---	-287	---	-170	---	-248	---	-285
Crossover Duct Temperature at Engine Start, °F[2]	TFTD-2	-100^{+25}_{-0}	-95	-100^{+25}_{-0}	-95	-100^{+25}_{-0}	-97	0 ± 25	-12	50 ± 25	33
	TFTD-3	↓	-91	↓	-94	↓	-89	↓	-1	↓	47
	TFTD-8	↓	-97	↓	-98	↓	-94	↓	-8	↓	37
Main Oxidizer Valve Control Line Temperature at Engine Start, °F		---	-8	---	27	---	-9	---	-15	---	-24
Main Oxidizer Valve Second-Stage Actuator Temperature at Engine Start, °F		-40^{+0}_{-20}	-84	-40^{+0}_{-20}	-88	-40^{+0}_{-20}	-70	-100 ± 50	-147	---	-153
Fuel Lead Time, sec[1]		1.0	1.009	1.0	1.002	1.0	1.000	1.0	1.002	1.0	1.007
Propellant in Engine Time, min		30 Minimum[2]	48	30 Minimum[2]	30	30 Minimum[2]	31	30 Minimum[3]	53	30	34
Propellant Recirculation Time, min		10	10	10	10	10	10	10	10	10	14
Prevalve Sequencing Logic		Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal
Gas Generator Oxidizer Supply Line Temperature at Engine Start, °F	TOBS-1	Above -100	36	Above -100	28	Above -100	11	Above -100	-5	Above -100	-5
	TOBS-2A	↓	29	↓	23	↓	21	↓	13	↓	9
	TOBS-3	---	4	---	0	---	-1	---	-8	---	-14
Start Tank Discharge Valve Opening Control Temperature at Engine Start, °F		50 ± 25	44	50 ± 25	35	50 ± 25	38	50 ± 25	38	50 ± 25	34
Vibration Safety Count Duration (msec) and Occurrence Time (sec) from t_0[1]		--- / ---	32 / 1.026	--- / ---	134 / 1.032	--- / ---	80 / 1.000	--- / ---	143 / 0.888	--- / ---	None / ---
Gas Generator Outlet Temperature, °F	Initial Peak	---	1230	---	1400	---	990	---	1630	---	1715 After Cutoff
	Second Peak	---	None	---	None	---	None	---	None	---	None
Main Chamber Ignition (PC-3 = 100 psia) Time, sec (Ref. t_0)[1]		---	1.028	---	1.033	---	0.997	---	0.993	---	---
Main Oxidizer Valve Second-Stage Initial Movement, sec (Ref. t_0)[1]		---	0.954	---	0.978	---	0.983	---	1.009	---	---
Main-Stage Pressure No. 2 "O.K." sec (Ref. t_0)[1]		---	1.830	---	1.954	---	1.737	---	1.710	---	---
550-psia Chamber Pressure Attained, sec (Ref. t_0)		---	2.208	---	2.241	---	2.083	---	2.058	---	---
Propellant Utilization Valve Position at Engine Start / Engine Start/t_0 + 10 sec		Null / Closed	Null / Closed	Null / ---	Null / ---	Null / ---	Null / ---	Null / ---	Null / ---	Null / ---	Null / ---

[1] Data reduced from oscillogram.

[2] Component conditioning to be maintained within limits for last 15 min before engine start.

[3] Varied to obtain desired main oxidizer valve second-stage actuator temperature limits at engine start.

TABLE VI
ENGINE VALVE TIMINGS

Firing Number J4-1801-	Start																							
	Start Tank Discharge Valve						Main Fuel Valve			Main Oxidizer Valve First Stage			Main Oxidizer Valve Second Stage			Gas Generator Fuel Poppet			Gas Generator Oxidizer Poppet			Oxidizer Turbine Bypass Valve		
	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec
A	0	0.139	0.125	0.450	0.094	0.236	-1.009	0.055	0.061	0.450	0.056	0.051	0.450	0.504	1.725	0.450	0.111	0.035	0.450	0.186	0.083	0.450	0.228	0.277
B	0	0.139	0.121	0.447	0.083	0.237	-1.002	0.055	0.064	0.447	0.058	0.051	0.447	0.531	1.691	0.447	0.111	0.030	0.447	0.183	0.084	0.447	0.223	0.277
C	0	0.138	0.122	0.447	0.082	0.237	-1.000	0.055	0.065	0.447	0.058	0.048	0.447	0.518	1.737	0.447	0.112	0.028	0.447	0.182	0.080	0.447	0.233	0.280
D	0	0.140	0.123	0.446	0.089	0.236	-1.002	0.057	0.066	0.448	0.058	0.058	0.446	0.563	1.830	0.446	0.116	0.030	0.446	0.184	0.067	0.446	0.226	0.273
E	0	0.145	0.134	0.447	0.088	0.233	-1.007	0.056	0.068	0.447	0.057	0.058	0.447	---	---	0.447	0.117	0.030	0.447	0.185	0.084	0.447	0.233	0.213
Pre-Fire Final Sequence	0	0.095	0.110	0.447	0.085	0.248	-1.000	0.042	0.070	0.447	0.050	0.055	0.447	0.495	1.355	0.447	0.080	0.030	0.447	0.148	0.067	0.447	0.230	0.260

Firing Number J4-1801-	Shutdown														
	Main Fuel Valve			Main Oxidizer Valve			Gas Generator Fuel Poppet			Gas Generator Oxidizer Poppet			Oxidizer Turbine Bypass Valve		
	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec
A	32.574	0.123	0.308	32.574	0.060	0.163	32.574	0.053	0.019	32.574	0.030	0.011	32.574	0.232	0.450
B	7.588	0.128	0.330	7.588	0.061	0.158	7.588	0.056	0.026	7.588	0.033	0.017	7.588	0.227	0.453
C	7.588	0.132	0.338	7.588	0.058	0.159	7.588	0.057	0.024	7.588	0.029	0.016	7.588	0.233	0.462
D	7.580	0.140	0.363	7.580	0.064	0.181	7.580	0.058	0.028	7.580	0.033	0.018	7.580	0.213	0.311
E	0.875	0.110	0.313	0.875	0.032	0.034	0.875	0.073	0.034	0.875	0.038	0.022	0.875	0.044	0.380
Pre-Fire Final Sequence	---	0.083	0.238	---	0.052	0.123	---	0.070	0.041	---	0.058	0.021	---	0.208	0.542

Notes: 1. All valve signal times are referenced to t_0.
2. Valve delay time is the time required for initial valve movement after the valve "open" or valve "closed" solenoid has been energized.
3. Final sequence check is conducted without propellants and within 12 hr prior to testing.
4. Data reduced from oscillogram.

TABLE VII
MAIN OXIDIZER VALVE TORQUE COMPARISONS AT INITIAL SECOND-STAGE MOVEMENT

Firing Number	Time of Initial Movement, sec (Ref. t_0)	Pressure Data at Initial Movement, psia				Torque on Valve Gate, in. -lb_f		
		PC-3	POPD-2	PHRO-1A	POVCC	Actuator	Hydraulic	Net Opening (Frictional)
20A	0.954	35.5	175	398	336	197	108	89
20B	0.978	32.5	171	402	334	258	107	151
20C	0.963	40.4	202	401	336	220	124	96
20D	1.009	109	200	401	337	215	70	145

Note: See Appendix IV for torque calculations.

TABLE VIII
ENGINE PERFORMANCE SUMMARY

Firing Number J4-1801-20A		Site	Normalized
Time, sec		29.5	29.5
Overall Engine Performance	Thrust, lb_f	225,400	223,600
	Chamber Pressure, psia	757.8	748.6
	Mixture Ratio	5.669	5.670
	Fuel Weight Flow, lb_m/sec	79.2	78.2
	Oxidizer Weight Flow, lb_m/sec	449.0	443.7
	Total Weight Flow, lb_m/sec	528.2	521.9
Thrust Chamber Performance	Mixture Ratio	5.874	5.877
	Total Weight Flow, lb_m/sec	521.6	515.4
	Characteristic Velocity, ft/sec	7954	7952
Fuel Turbopump Performance	Pump Efficiency, percent	73.0	73.0
	Pump Speed, rpm	26,230	26,089
	Turbine Efficiency, percent	59.0	58.9
	Turbine Pressure Ratio	7.23	7.23
	Turbine Inlet Temperature, °F	1281	1266
	Turbine Weight Flow, lb_m/sec	6.61	6.56
Oxidizer Turbopump Performance	Pump Efficiency, percent	80.3	80.3
	Pump Speed, rpm	8459	8401
	Turbine Efficiency, percent	46.9	46.7
	Turbine Pressure Ratio	2.64	2.64
	Turbine Inlet Temperature, °F	858	846
	Turbine Weight Flow, lb_m/sec	5.86	5.82
Gas Generator Performance	Mixture Ratio	0.988	0.979
	Chamber Pressure, psia	642.5	640.6

Notes:
1. Site data are calculated from test data.
2. Normalized data are corrected to standard pump inlet and engine ambient vacuum conditions.
3. Input data are test data averaged from 29 to 30 sec.
4. Site and normalized data were computed using the Rocketdyne PAST 640 modification zero computer program.

APPENDIX III
INSTRUMENTATION

The instrumentation for AEDC test J4-1801-20 is tabulated in Table III-I. The location of selected major engine instrumentation is shown in Fig. III-1.

TABLE III-1
INSTRUMENTATION LIST

AEDC Code	Parameter	Tap No.	Range	Micro-SADIC	Magnetic Tape	Oscillograph	Strip Chart	X-Y Plotter
	Current		amp					
ICC	Control		0 to 30	x		x		
IIC	Ignition		0 to 30	x		x		
	Event							
EECL	Engine Cutoff Lockin		On/Off	x		x		
EECO	Engine Cutoff Signal		On/Off	x	x	x		
EES	Engine Start Command		On/Off	x		x		
EFBVC	Fuel Bleed Valve Closed Limit		Open/Closed	x				
EFJT	Fuel Injector Temperature		On/Off	x		x		
EFPVC/O	Fuel Prevalve Closed/Open Limit		Closed/Open	x		x		
EHCS	Helium Control Solenoid		On/Off	x		x		
EID	Ignition Detected		On/Off	x		x		
EIPCS	Ignition Phase Control Solenoid		On/Off	x		x		
EMCS	Main-Stage Control Solenoid		On/Off	x		x		
EMP-1	Main-Stage Pressure No. 1		On/Off	x		x		
EMP-2	Main-Stage Pressure No. 2		On/Off	x		x		
EOBVC	Oxidizer Bleed Valve Closed Limit		Open/Closed	x				
EOPVC	Oxidizer Prevalve Closed Limit		Closed	x		x		
EOPVO	Oxidizer Prevalve Open Limit		Open	x		x		
ESTDCS	Start Tank Discharge Control Solenoid		On/Off	x	x	x		
	Sparks							
RASIS-1	Augmented Spark Igniter Spark No. 1		On/Off			x		
RASIS-2	Augmented Spark Igniter Spark No. 2					x		
RGGS-1	Gas Generator Spark No. 1		On/Off			x		
RGGS-2	Gas Generator Spark No. 2		On/Off			x		
	Flows		gpm					
QF-1A	Fuel	PFF	0 to 9000	x		x		
QF-2	Fuel	PFFA	0 to 9000	x	x	x		
QFRP	Fuel Recirculation		0 to 160	x				
QO-1A	Oxidizer	POF	0 to 3000	x		x		
QO-2	Oxidizer	POFA	0 to 3000	x	x	x		
QORP	Oxidizer Recirculation		0 to 50	x			x	
	Position		Percent Open					
LFVT	Main Fuel Valve		0 to 100	x		x		
LGGVT	Gas Generator Valve		0 to 100	x		x		
LOTBVT	Oxidizer Turbine Bypass Valve		0 to 100	x		x		
LOVT	Main Oxidizer Valve		0 to 100	x	x	x		
LPUTOP	Propellant Utilization Valve		0 to 100	x		x	x	
LSTDVT	Start Tank Discharge Valve		0 to 100	x		x		

TABLE III-1 (Continued)

AEDC Code	Parameter	Tap No.	Range	Micro-SADIC	Magnetic Tape	Oscillo-graph	Strip Chart	X-Y Plotter
	Pressure		psia					
PA1	Test Cell		0 to 0.5	x		x		
PA2	Test Cell		0 to 1.0	x	x			
PA3	Test Cell		0 to 5.0	x			x	
PC-1P	Thrust Chamber	CG1	0 to 1000	x			x	
PC-3	Thrust Chamber	CG1A	0 to 1000	x	x	x		
PCGG-2	Gas Generator Chamber	GG1A	0 to 1000	x				
PFASIJ	Augmented Spark Igniter Fuel Injection		0 to 1000	x				
PFJ-1A	Main Fuel Injection	CF2	0 to 1000	x		x		
PFJ-2	Main Fuel Injection	CF2A	0 to 1000	x	x			
PFJGG-1A	Gas Generator Fuel Injection	GF4	0 to 1000	x				
PFJGG-2	Gas Generator Fuel Injection	GF4	0 to 1000	x		x		
PFMI	Fuel Jacket Inlet Manifold	CF1	0 to 2000	x				
PFOI-1A	Fuel Tapoff Orifice Outlet	HF2	0 to 1000	x				
PFPC-1A	Fuel Pump Balance Piston Cavity	PF5	0 to 1000	x				
PFPD-1P	Fuel Pump Discharge	PF3	0 to 1500	x				
PFPD-2	Fuel Pump Discharge	PF2	0 to 1500	x	x	x		
PFPI-1	Fuel Pump Inlet		0 to 100	x				x
PFPI-2	Fuel Pump Inlet		0 to 200	x				x
PFPI-3	Fuel Pump Inlet		0 to 200		x	x		
PFPS-1P	Fuel Pump Interstage	PF6	0 to 200	x				
PFRPO	Fuel Recirculation Pump Outlet		0 to 60	x				
PFRPR	Fuel Recirculation Pump Return		0 to 50	x				
PFST-1P	Fuel Start Tank	TF1	0 to 1500	x		x		
PFST-2	Fuel Start Tank	TF1	0 to 1500	x				x
PFUT	Fuel Tank Ullage		0 to 100	x				
PFVI	Fuel Tank Repressurization Line Nozzle Inlet		0 to 1000	x				
PFVL	Fuel Tank Repressurization Line Nozzle Throat		0 to 1000	x				
PHECMO	Pneumatic Control Module Outlet		0 to 750	x				
PHEOP	Oxidizer Recirculation Pump Purge		0 to 150	x				
PHET-1P	Helium Tank	NN1	0 to 3500	x		x		
PHET-2	Helium Tank	NN1	0 to 3500	x				x
PHRO-1A	Helium Regulator Outlet	NN2	0 to 750	x	x			
POBSC	Oxidizer Bootstrap Conditioning		0 to 50	x				
POBV	Gas Generator Oxidizer Bleed Valve	GO2	0 to 2000	x				
POJ-1A	Main Oxidizer Injection	CO3	0 to 1000	x				
POJ-2	Main Oxidizer Injection	CO3A	0 to 1000	x		x		
POJGG-1A	Gas Generator Oxidizer Injection	GO5	0 to 1000	x		x		

TABLE III-1 (Continued)

AEDC Code	Parameter	Tap No.	Range	Micro-SADIC	Magnetic Tape	Oscillo-graph	Strip Chart	X-Y Plotter
	Pressure							
POJGG-2	Gas Generator Oxidizer Injection	GO5	0 to 1000	x				
POPBC-1A	Oxidizer Pump Bearing Coolant	PO7	0 to 500	x				
POPD-1P	Oxidizer Pump Discharge	PO3	0 to 1500	x				
POPD-2	Oxidizer Pump Discharge	PO2	0 to 1500	x	x	x		
POPI-1	Oxidizer Pump Inlet		0 to 100	x				x
POPI-2	Oxidizer Pump Inlet		0 to 200	x				x
POPI-3	Oxidizer Pump Inlet		0 to 100			x		
POPSC-1A	Oxidizer Pump Primary Seal Cavity	PO6	0 to 50	x				
PORPO	Oxidizer Recirculation Pump Outlet		0 to 115	x				
PORPR	Oxidizer Recirculation Pump Return		0 to 100	x				
POTI-1A	Oxidizer Turbine Inlet	TG3	0 to 200	x				
POTO-1A	Oxidizer Turbine Outlet	TG4	0 to 100	x				
POUT	Oxidizer Tank Ullage		0 to 100	x				
POVCC	Main Oxidizer Valve Closing Control		0 to 500	x	x			
POVI	Oxidizer Tank Repressurization Line Nozzle Inlet		0 to 1000	x				
POVL	Oxidizer Tank Repressurization Line Nozzle Throat		0 to 1000	x				
PPUVI-1A	Propellant Utilization Valve Inlet	PO6	0 to 1000	x				
PPUVO-1A	Propellant Utilization Valve Outlet	PO9	0 to 500	x				
PTCFJP	Thrust Chamber Fuel Jacket Purge		0 to 100	x				
PTPP	Turbopump and Gas Generator Purge		0 to 250	x				
	Speeds		rpm					
NFP-1P	Fuel Pump	PFV	0 to 30,000	x	x	x		
NFRP	Fuel Recirculation Pump		0 to 15,000	x				
NOP-1P	Oxidizer Pump	POV	0 to 12,000	x	x	x		
NORP	Oxidizer Recirculation Pump		0 to 15,000	x				
	Temperatures		°F					
TA1	Test Cell (North)		-50 to +800	x				
TA2	Test Cell (East)		-50 to +800	x				
TA3	Test Cell (South)		-50 to +800	x				
TA4	Test Cell (West)		-50 to +800	x				
TAIP-1A	Auxiliary Instrument Package		-320 to -200	x				
TBHR-1	Helium Regulator Body (North Side)		-100 to +50	x				
TBHR-2	Helium Regulator Body (South Side)		-100 to +50	x			x	
TBSC	Oxidizer Bootstrap Conditioning		-350 to +150	x				
TCLC	Main Oxidizer Valve Closing Control Line Conditioning		-325 to +200	x				

TABLE III-1 (Continued)

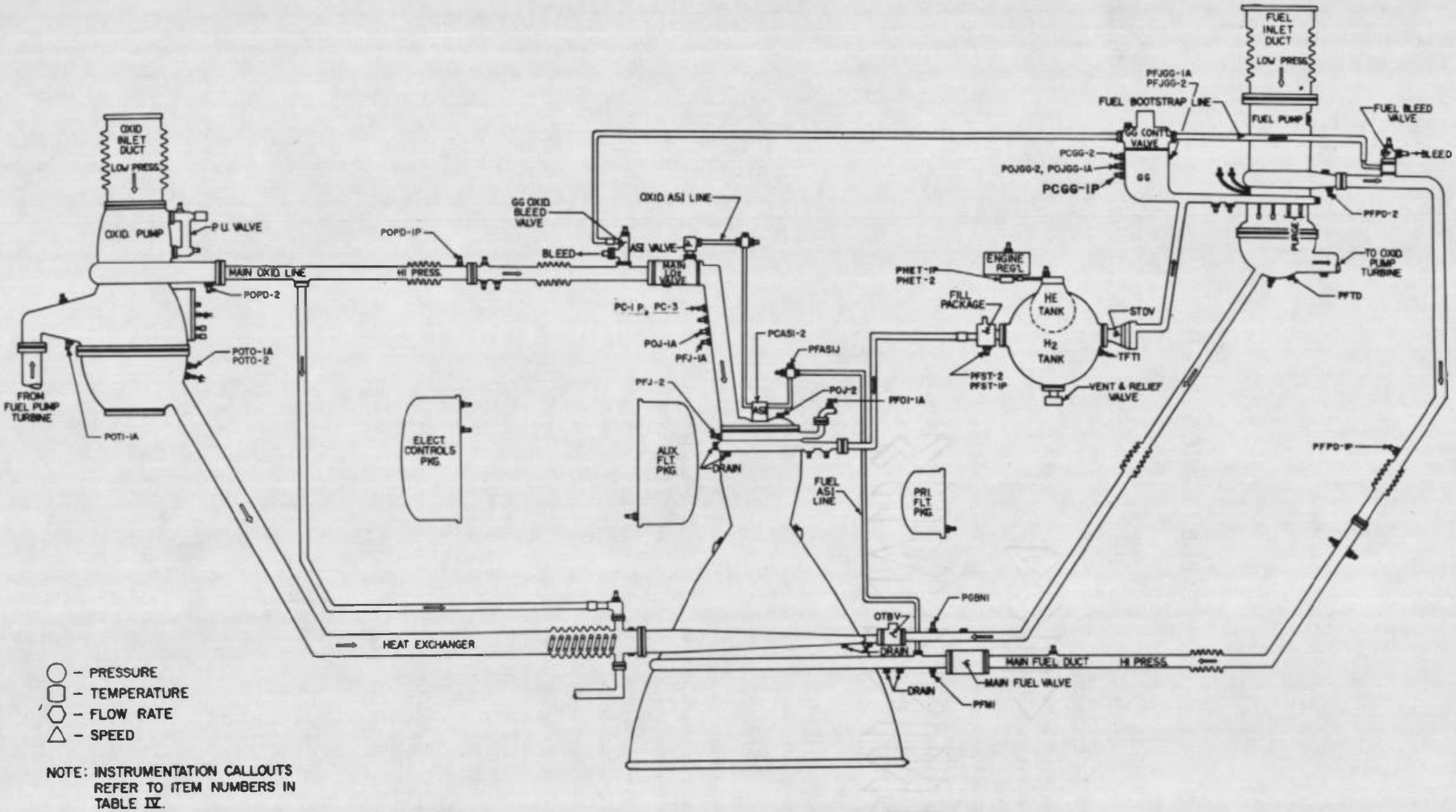
AEDC Code	Parameter	Tap No.	Range	Micro-SADIC	Magnetic Tape	Oscillo-graph	Strip Chart	X-Y Plotter
	Temperatures		°F					
TECP-1P	Electrical Controls Package	NST1A	-300 to +200	x			x	
TFASIJ	Augmented Spark Igniter Fuel Injection	IFT1	-425 to +100	x		x		
TFBV-1A	Fuel Bleed Valve	GFT1	-425 to -375	x				
TFJ-1P	Main Fuel Injection	CFT2	-425 to +250	x	x	x		
TFPD-1P	Fuel Pump Discharge	PFT1	-425 to -400	x	x	x		
TFPD-2	Fuel Pump Discharge	PFT1	-425 to -400	x				
TFPDD	Fuel Pump Discharge Duct		-320 to +300	x				
TFPI-1	Fuel Pump Inlet		-425 to -400	x				x
TFPI-2	Fuel Pump Inlet		-425 to -400	x				x
TFRPO	Fuel Recirculation Pump Outlet		-425 to -410	x				
TFRPR	Fuel Recirculation Pump Return Line		-425 to -250	x				
TFRT-1	Fuel Tank		-425 to -410	x				
TFRT-2	Fuel Tank		-425 to -410	x				
TFST-1P	Fuel Start Tank	TFT1	-350 to +100	x				
TFST-2	Fuel Start Tank	TFT1	-350 to +100	x				x
TFTD-1	Fuel Turbine Discharge Duct		-200 to +800	x				
TFTD-1R	Fuel Turbine Discharge Collector		-200 to +900	x				
TFTD-2	Fuel Turbine Discharge Duct		-200 to +1000	x			x	
TFTD-3	Fuel Turbine Discharge Duct		-200 to +1000	x			x	
TFTD-3R	Fuel Turbine Discharge Line		-200 to +900	x				
TFTD-4	Fuel Turbine Discharge Duct		-200 to +1000	x				
TFTD-4R	Fuel Turbine Discharge Line		-200 to +900	x				
TFTD-5	Fuel Turbine Discharge Duct		-200 to +1400	x				
TFTD-6	Fuel Turbine Discharge Duct		-200 to +1400	x				
TFTD-7	Fuel Turbine Discharge Duct		-200 to +1400	x				
TFTD-8	Fuel Turbine Discharge Duct		-200 to +1400	x			x	
TFTI-1P	Fuel Turbine Inlet	TFT1	0 to 1800	x			x	
TFTO	Fuel Turbine Outlet	TFT2	0 to 1800	x				
TGGO-1A	Gas Generator Outlet	GGT1	0 to 1800	x	x	x		
THET-1P	Helium Tank	NNT1	-350 to +100	x				x
TMOVC	Main Oxidizer Valve Actuator Conditioning		-325 to +200	x				
TOBS-1	Oxidizer Bootstrap Line		-300 to +250	x				
TOBS-2	Oxidizer Bootstrap Line		-300 to +250	x				
TOBS-2A	Oxidizer Bootstrap Line		-300 to +250	x				
TOBS-2B	Oxidizer Bootstrap Line		-300 to +250	x				
TOBS-3	Oxidizer Bootstrap Line		-300 to +250	x				
TOBS-4	Oxidizer Bootstrap Line		-300 to +250	x				
TOBS-5	Oxidizer Bootstrap Line		-300 to +250	x				
TOBSCI	Oxidizer Bootstrap Conditioning Inlet		0 to 100	x				
TOBSCO	Oxidizer Bootstrap Conditioning Outlet		0 to 100	x				
TOBV-1A	Oxidizer Bleed Valve	GOT2	-300 to -250	x				

TABLE III-1 (Continued)

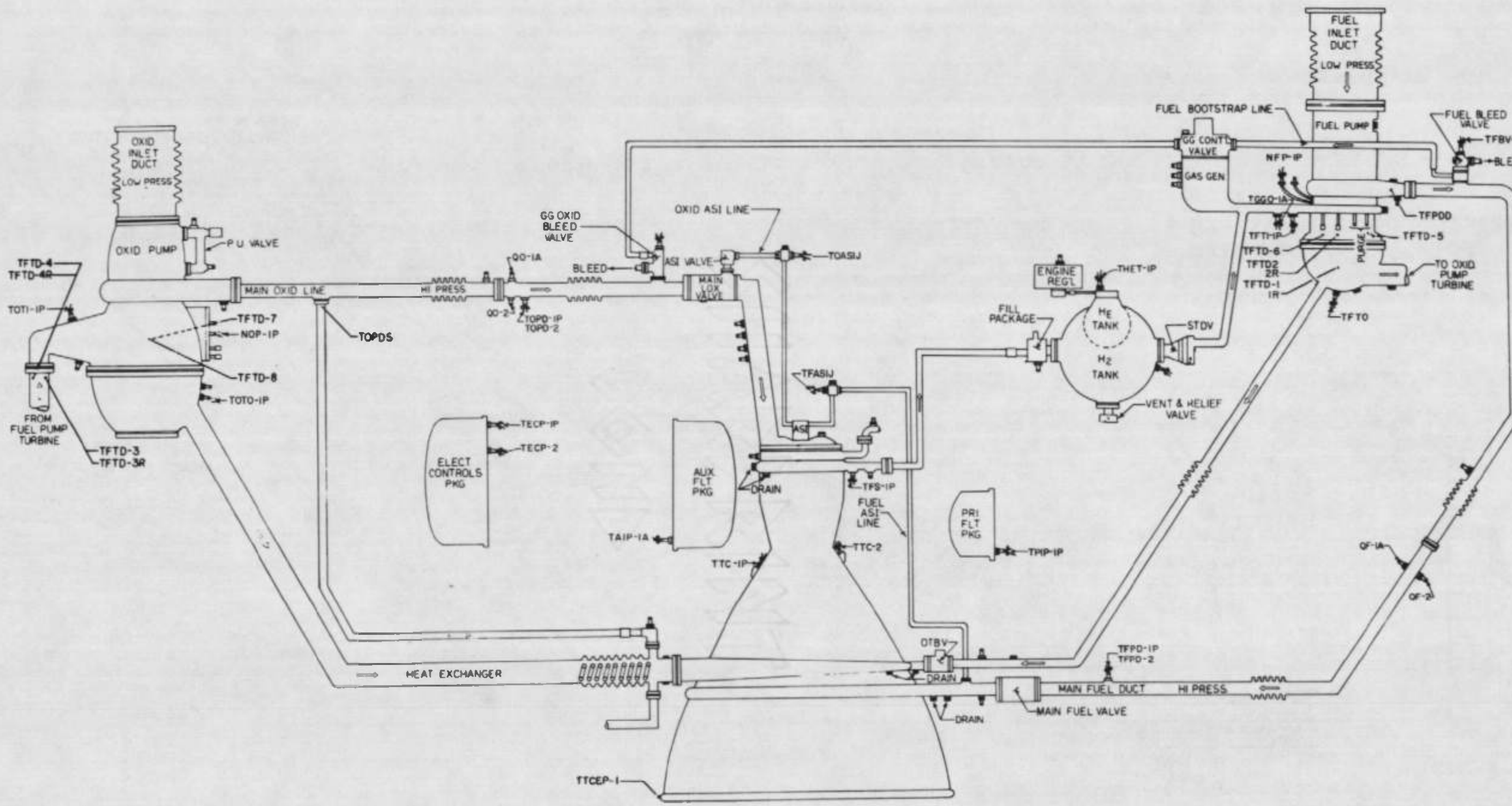
AEDC Code	Parameter	Tap No.	Range	Micro-SADIC	Magnetic Tape	Oscillo-graph	Strip Chart	X-Y Plotter
	Temperatures		°F					
TOPB-1A	Oxidizer Pump Bearing Coolant	POT4	-300 to -250	x				
TOPD-1P	Oxidizer Pump Discharge	POT3	-300 to -250	x	x	x	x	
TOPD-2	Oxidizer Pump Discharge	POT3	-300 to -250	x				
TOPDS	Oxidizer Pump Discharge Skin		-300 to -100	x				
TOPI-1	Oxidizer Pump Inlet		-310 to -270	x				x
TOPI-2	Oxidizer Pump Inlet		-310 to -270	x				x
TORPO	Oxidizer Recirculation Pump Outlet		-300 to -250	x				
TORPR	Oxidizer Recirculation Pump Return		-300 to -140	x				
TORT-1	Oxidizer Tank		-300 to -287	x				
TORT-3	Oxidizer Tank		-300 to -287	x				
TOTI-1P	Oxidizer Turbine Inlet	TGT3	0 to 1200	x			x	
TOTO-1P	Oxidizer Turbine Outlet	TGT4	0 to 1000	x				
TOVL	Oxidizer Tank Repressurization Line Nozzle Throat		-300 to +100	x				
TPIP-1P	Primary Instrument Package		-300 to +200	x				
TPPC	Pneumatic Package Conditioning		-325 to +200	x				
TSC2-1	Thrust Chamber Skin		-350 to +500	x				
TSC2-2	Thrust Chamber Skin		-350 to -500	x				
TSC2-3	Thrust Chamber Skin		-350 to -500	x				
TSC2-4	Thrust Chamber Skin		-350 to +500	x				
TSC2-5	Thrust Chamber Skin		-350 to +500	x				
TSC2-6	Thrust Chamber Skin		-350 to +500	x				
TSC2-7	Thrust Chamber Skin		-350 to +500	x				
TSC2-8	Thrust Chamber Skin		-350 to +500	x				
TSC2-9	Thrust Chamber Skin		-350 to +500	x				
TSC2-10	Thrust Chamber Skin		-350 to +500	x				
TSC2-11	Thrust Chamber Skin		-350 to +500	x				
TSC2-12	Thrust Chamber Skin		-350 to +500	x				
TSC2-13	Thrust Chamber Skin		-350 to +500	x			x	
TSC2-14	Thrust Chamber Skin		-350 to +500	x				
TSC2-15	Thrust Chamber Skin		-350 to +500	x				
TSC2-16	Thrust Chamber Skin		-350 to +500	x				
TSC2-17	Thrust Chamber Skin		-350 to +500	x				
TSC2-18	Thrust Chamber Skin		-350 to +500	x				
TSC2-19	Thrust Chamber Skin		-350 to +500	x				
TSC2-20	Thrust Chamber Skin		-350 to +500	x				
TSC2-21	Thrust Chamber Skin		-350 to +500	x				
TSC2-22	Thrust Chamber Skin		-350 to +500	x				
TSC2-23	Thrust Chamber Skin		-350 to +500	x				
TSC2-24	Thrust Chamber Skin		-350 to +500	x				
TSOVAL-1	Oxidizer Valve Closing Control Line		-200 to +100	x				

TABLE III-1 (Concluded)

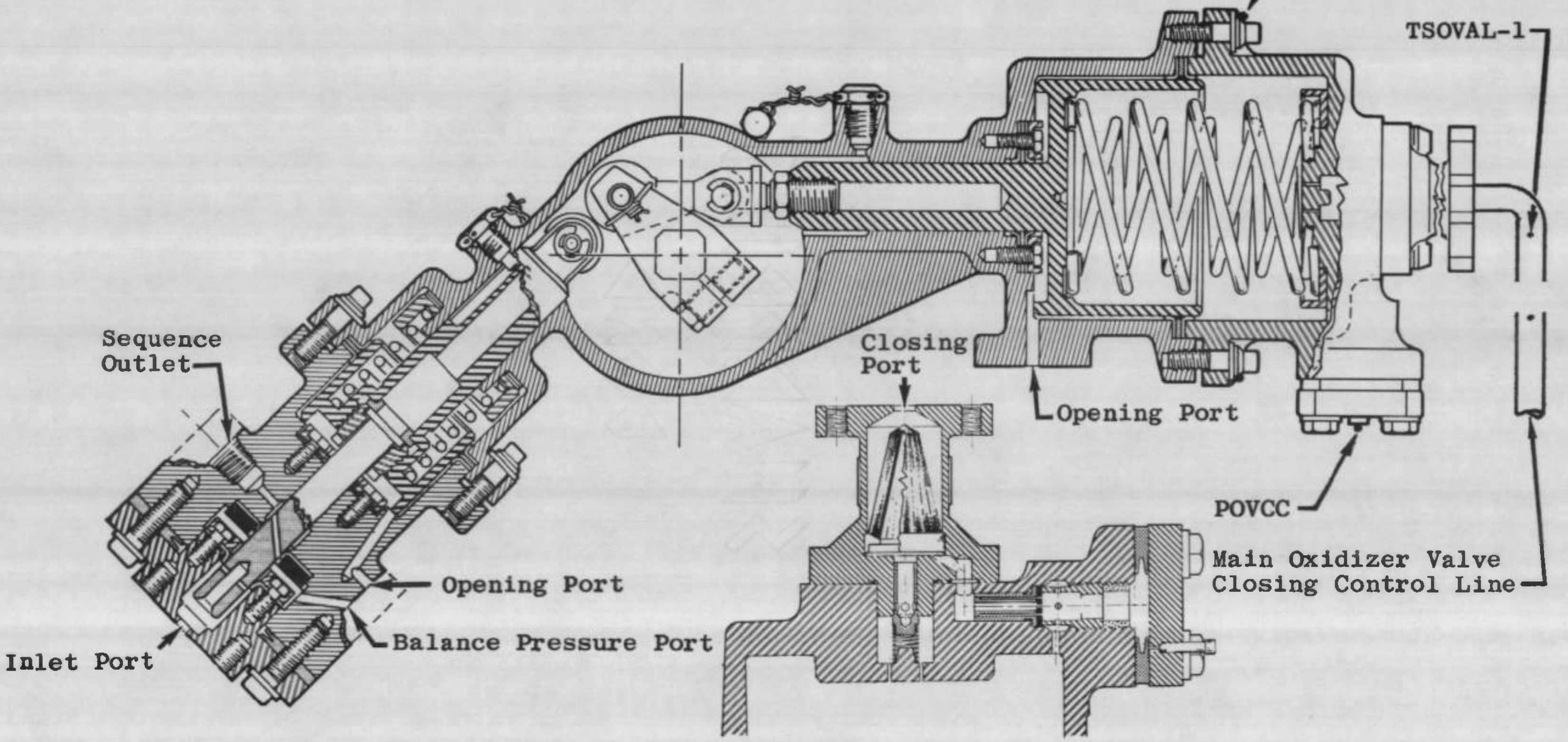
AEDC Code	Parameter	Tap No.	Range	Micro-SADIC	Magnetic Tape	Oscillograph	Strip Chart	X-Y Plotter
	Temperatures		°F					
TSOVC-1	Oxidizer Valve Actuator Cap		-325 to +150	x				
TSOVC-2	Oxidizer Valve Actuator Filter Flange		-325 to +150	x				
TSTC	Start Tank Conditioning		-350 to +150	x				
TSTDVCC	Start Tank Discharge Valve Closing Control Port		-350 to +100	x				
TSTDVOC	Start Tank Discharge Valve Opening Control Port		-350 to +100	x				
TTC-1P	Thrust Chamber Jacket (Control)	CS1	-425 to +500	x			x	
TTCEP-1	Thrust Chamber Exit		-425 to +500	x				
TXOC	Crossover Duct Conditioning		-325 to +200	x				
	Vibrations		g					
UFPR	Fuel Pump Radial 90 deg.		±200		x			
UOPR	Oxidizer Pump Radial 90 deg		±200		x			
UTCD-1	Thrust Chamber Dome		±500		x	x		
UTCD-2	Thrust Chamber Dome		±500		x	x		
UTCD-3	Thrust Chamber Dome		±500		x	x		
U1VSC	No. 1 Vibration Safety Counts		On/Off			x		
U2VSC	No. 2 Vibration Safety Counts		On/Off			x		
	Voltage		Volts					
VCB	Control Bus		0 to 36	x		x		
VIB	Ignition Bus		0 to 36	x		x		
VIDA	Ignition Detect Amplifier		9 to 16	x		x		
VPUTEP	Propellant Utilization Valve Excitation		0 to 5	x				



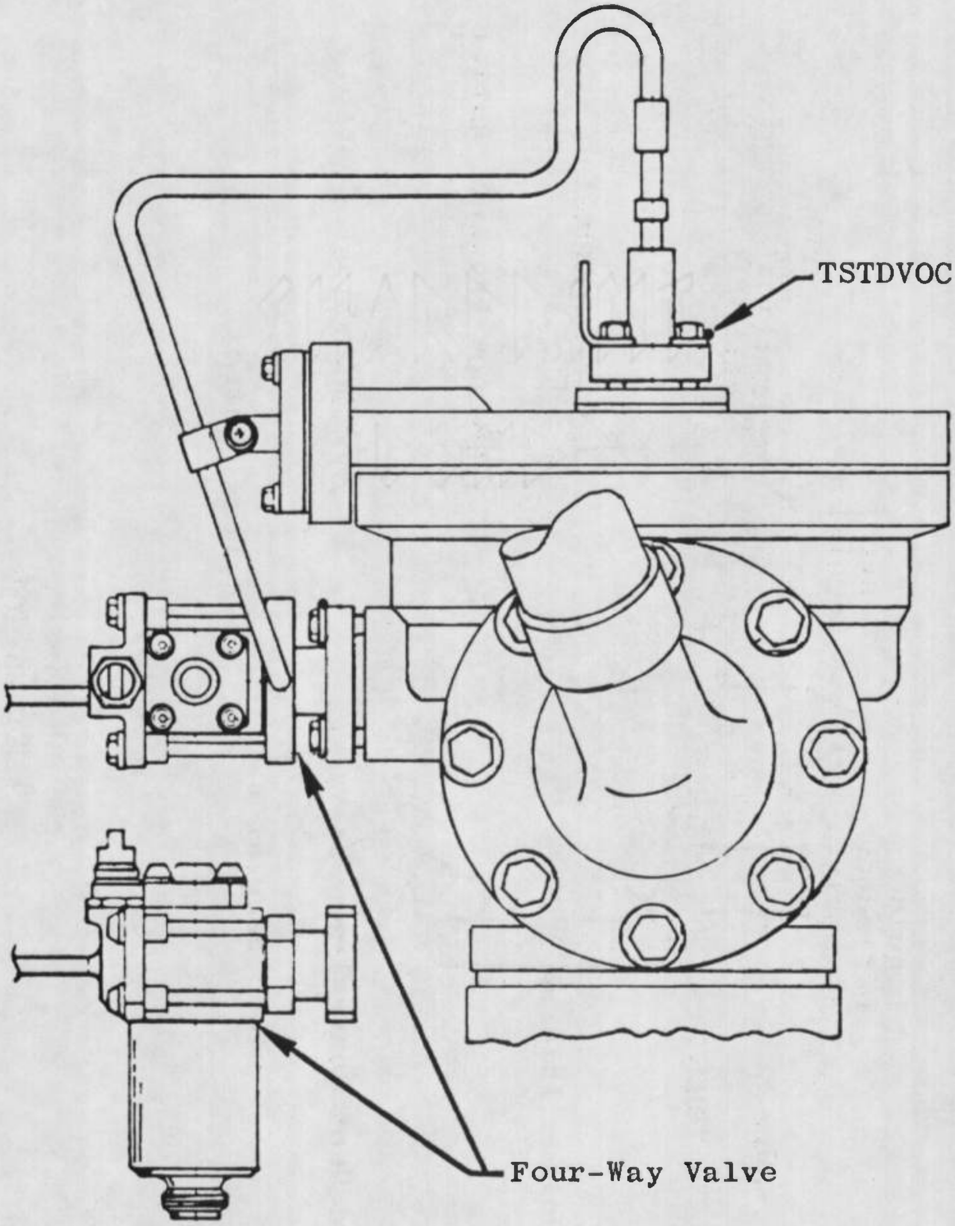
a. Engine Pressure Tap Locations
Fig. III-1 Instrumentation Locations



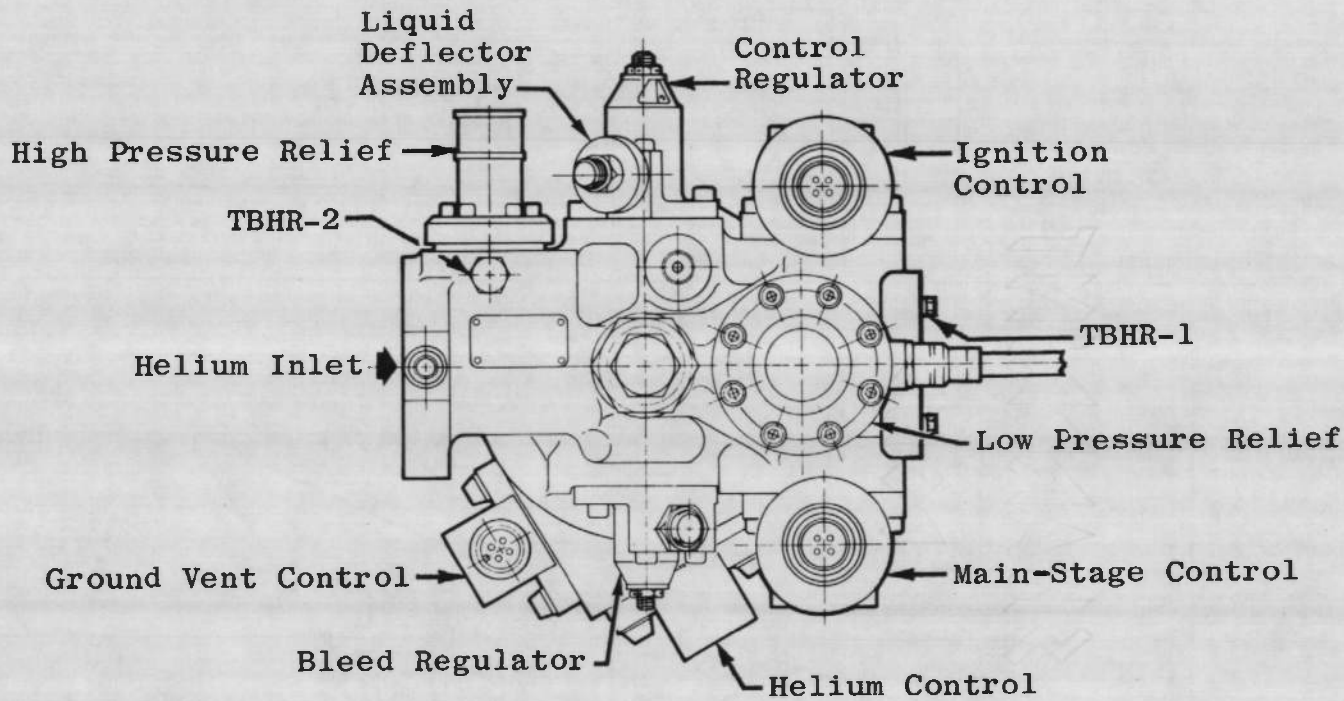
b. Engine Temperature, Flow, and Speed Instrumentation Locations
Fig. III-1 Continued



c. Main Oxidizer Valve
Fig. III-1 Continued

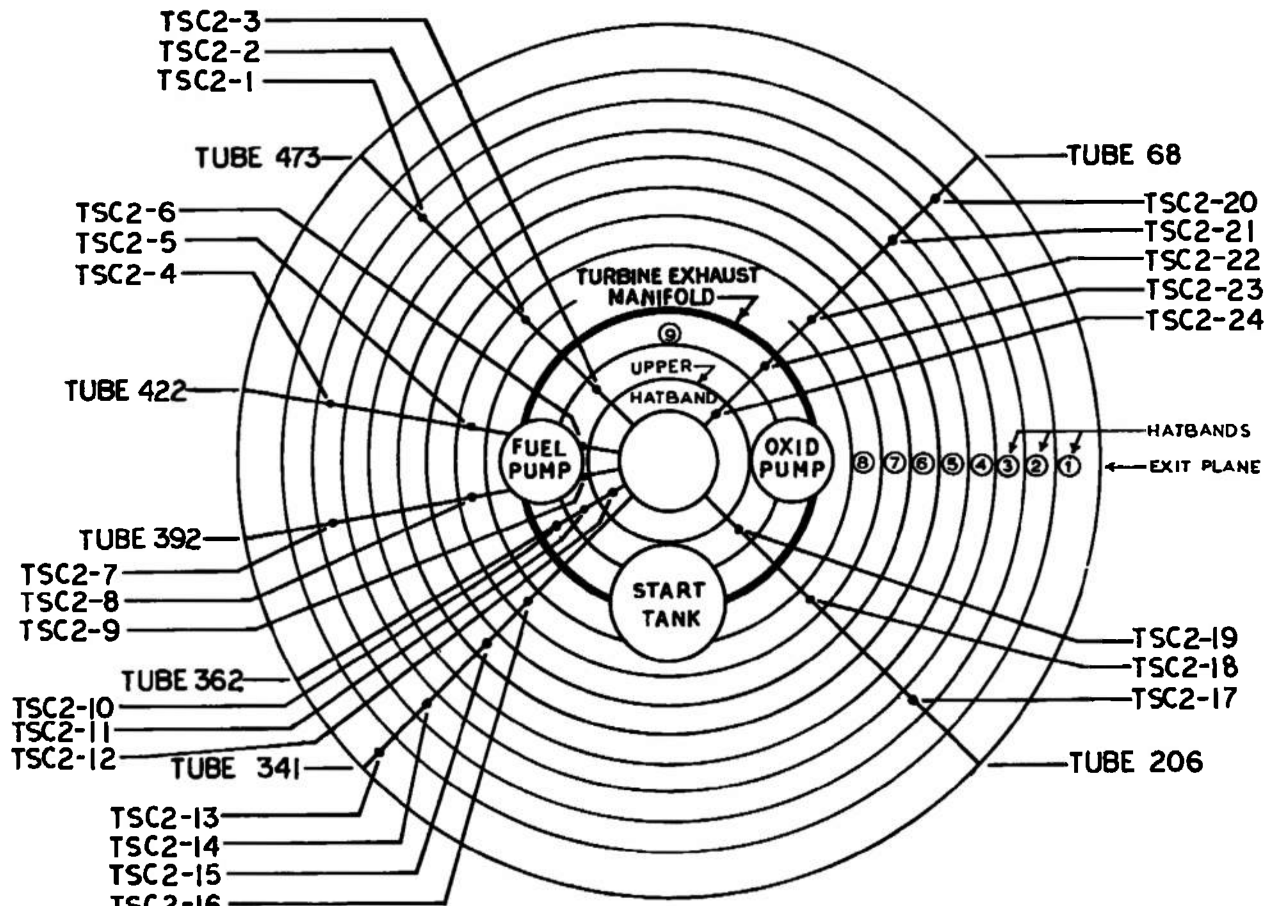


d. Start Tank Discharge Valve
Fig. III-1 Continued



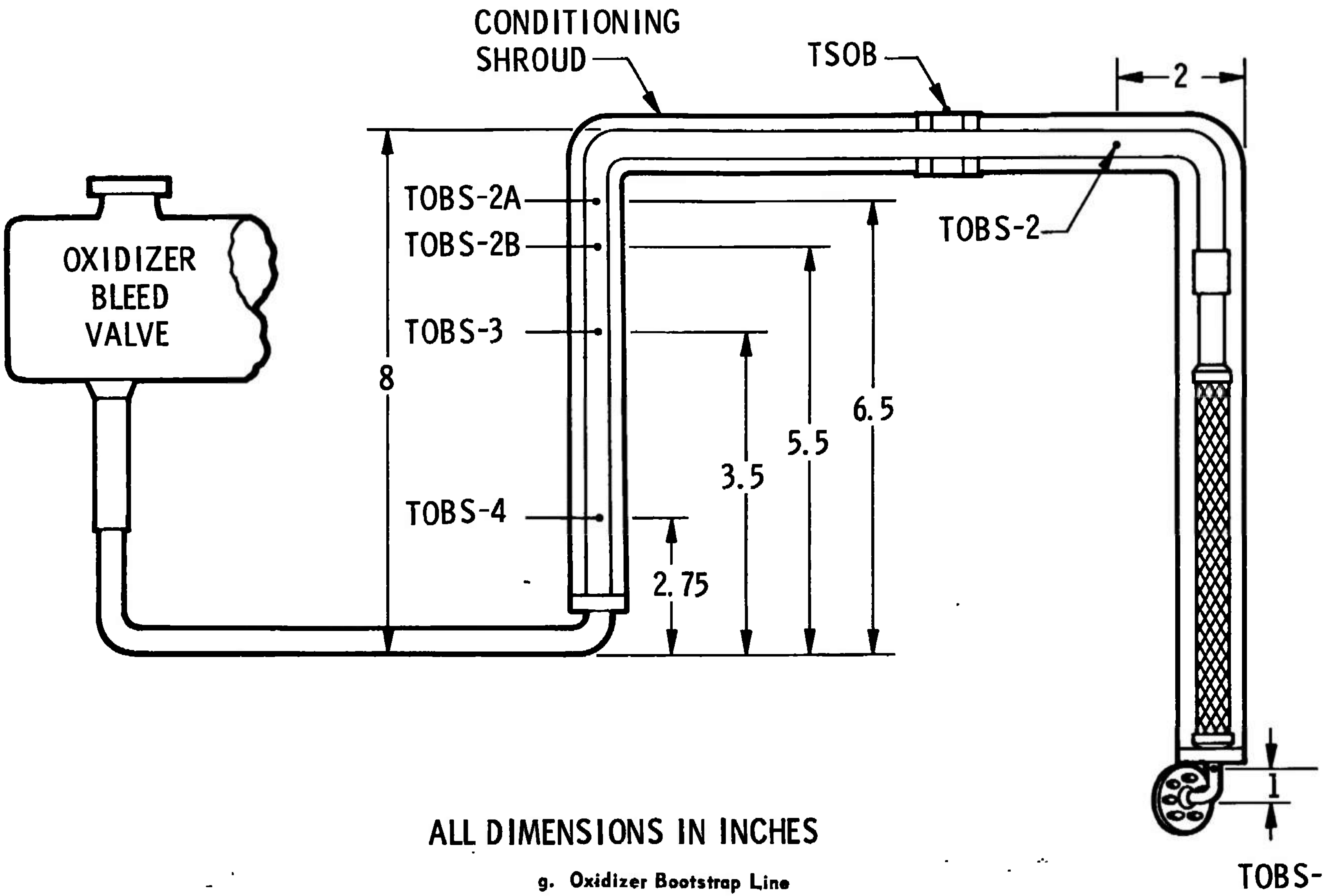
Top View

e. Helium Regulator
Fig. III-1 Continued



VIEW LOOKING AFT

f. Thrust Chamber
Fig. III-1 Continued



ALL DIMENSIONS IN INCHES

g. Oxidizer Bootstrap Line
Fig. III-1 Concluded

APPENDIX IV
METHODS OF CALCULATIONS
(MAIN OXIDIZER VALVE TORQUE)

TABLE IV-1
DATA INPUTS

Item No.	Parameter[1]
1	Oxidizer Pump Discharge Pressure (POPD-2)
2[2]	Thrust Chamber (Injector Face) Pressure (PC-3)
3	Helium Regulator Outlet Pressure (PHRO-1A)
4	Main Oxidizer Valve Closing Control Pressure (POVCC)

[1] Refer to Appendix III for parameter locations.

[2] Thrust chamber pressure is used instead of oxidizer injector pressure because of its better transient response characteristics.

Hydraulic Torque

The torque attributable to valve geometry and pressure drop across the valve which tends to open or close the valve. Using POPD minus PC, the engine manufacturer computes hydraulic torque as

Hydraulic Torque = 0.769 (POPD-PC) in. -lb_f at the 14-deg position. When the valve is at the 14-deg position, the torque acts in the closing direction.

Pneumatic Torque

The valve is opened (ramped) from the 14-deg position by application of regulated 400-psia opening pressure (PHRO-1A) and controlled venting of closing control pressure (POVCC) through an orifice to ambient (vent port check valve cracking pressure).

$$\text{Pneumatic Torque} = L\left[(9.0 \times \text{PHRO-1A}) - (9.797 \times \text{POVCC}) - 100 - X(K)\right] \text{ in.-lb}_f$$

where L = Actuator moment arm

$$= 1.250 (\sin 45 \text{ deg} + \theta)$$

(9.0 x PHRO-1A) = Opening Control Pressure-Area Term

(9.797 x POVCC) = Closing Control Pressure-Area Term

100 = Actuator Spring Pre-Load Compression Force (set on assembly)

X = Actuator Spring Deflection

= 0.8839 - 1.25 cos (45 deg + θ)

K = Actuator Spring Deflection

= 38.7 lb_f/in.

θ = Valve Angular Position, deg

Net Opening Torque

Summation of torques acting on the valve must equal or just exceed the torque caused by friction for the valve to begin second-stage movement.

Net Opening Torque = Pneumatic Torque - Hydraulic Torque $\geq$ Frictional Torque

APPENDIX V
METHODS OF CALCULATIONS
(PERFORMANCE PROGRAM NORMALIZED DATA)

TABLE V-1
PERFORMANCE PROGRAM DATA INPUTS

Item No.	Parameter
1	Thrust Chamber (Injector Face) Pressure, psia
2	Thrust Chamber Fuel and Oxidizer Injection Pressures, psia
3	Thrust Chamber Fuel Injection Temperature, °F
4	Fuel and Oxidizer Flowmeter Speeds, Hz
5	Fuel and Oxidizer Engine Inlet Pressures, psia
6	Fuel and Oxidizer Pump Discharge Pressures, psia
7	Fuel and Oxidizer Engine Inlet Temperatures, °F
8	Fuel and Oxidizer (Main Valves) Temperatures, °F
9	Propellant Utilization Valve Center Tap Voltage, volts
10	Propellant Utilization Valve Position, volts
11	Fuel and Oxidizer Pump Speeds, rpm
12	Gas Generator Chamber Pressure, psia
13	Gas Generator (Bootstrap Line at Bleed Valve) Temperature, °F
14	Fuel* and Oxidizer Turbine Inlet Pressure, psia
15	Oxidizer Turbine Discharge Pressure, psia
16	Fuel and Oxidizer Turbine Inlet Temperature, °F
17	Oxidizer Turbine Discharge Temperature, °F

*At AEDC, fuel turbine inlet pressure is estimated from gas generator chamber pressure.

NOMENCLATURE

A	Area, in.^{2}
B	Horsepower, hp
C*	Characteristic velocity, ft/sec
C_p	Specific heat at constant pressure, Btu/lb/°F
D	Diameter, in.
H	Head, ft
h	Enthalpy, Btu/lb_m
M	Molecular weight
N	Speed, rpm
P	Pressure, psia
Q	Flow rate, gpm
R	Resistance, sec^2/ft^3-in.^{2}
r	Mixture ratio
T	Temperature, °F
TC*	Theoretical characteristic velocity, ft/sec
W	Weight flow, lb/sec
Z	Pressure drop, psi
β	Ratio
γ	Ratio of specific heats
η	Efficiency
θ	Valve position, deg
ρ	Density, lb/ft^3

SUBSCRIPTS

A	Ambient
AA	Ambient at thrust chamber exit
B	Bypass nozzle

BIR	Bypass nozzle inlet (Rankine)
BNI	Bypass nozzle inlet (total)
C	Thrust chamber
CF	Thrust chamber, fuel
CO	Thrust chamber, oxidizer
CV	Thrust chamber, vacuum
E	Engine
EF	Engine fuel
EM	Engine measured
EO	Engine oxidizer
EV	Engine, vacuum
e	Exit
em	Exit measured
F	Thrust
FIT	Fuel turbine inlet
FM	Fuel measured
FY	Thrust, vacuum
f	Fuel
G	Gas generator
GF	Gas generator fuel
GO	Gas generator oxidizer
H1	Hot gas duct No. 1
H1R	Hot gas duct No. 1 (Rankine)
H2R	Hot gas duct No. 2 (Rankine)
IF	Inlet fuel
IO	Inlet oxidizer
ITF	Isentropic turbine fuel
ITO	Isentropic turbine oxidizer
N	Nozzle
NB	Bypass nozzle (throat)

NV	Nozzle, vacuum
O	Oxidizer
OC	Oxidizer pump calculated
OF	Outlet fuel pump
OFIS	Outlet fuel pump isentropic
OM	Oxidizer measured
OO	Oxidizer outlet
PF	Pump fuel
PO	Pump oxidizer
PUVO	Propellant utilization valve oxidizer
RNC	Ratio bypass nozzle, critical
SC	Specific, thrust chamber
SCV	Specific thrust chamber, vacuum
SE	Specific, engine
SEV	Specific, engine vacuum
T	Total
T_o	Turbine oxidizer
TEF	Turbine exit fuel
TEFS	Turbine exit fuel (static)
TF	Fuel turbine
TIF	Turbine inlet fuel (total)
TIFM	Turbine inlet, fuel, measured
TIFS	Turbine inlet fuel isentropic
TIO	Turbine inlet oxidizer
t	Throat
V	Vacuum
v	Valve
XF	Fuel tank repressurant
XO	Oxidizer tank repressurant

PERFORMANCE PROGRAM EQUATIONS

MIXTURE RATIO

Engine

$$r_E = \frac{W_{EO}}{W_{EF}}$$

$$W_{EO} = W_{OM} - W_{XO}$$

$$W_{EF} = W_{FM} - W_{XF}$$

$$W_E = W_{EO} + W_{EF}$$

Thrust Chamber

$$r_C = \frac{W_{CO}}{W_{CF}}$$

$$W_{CO} = W_{OM} - W_{XO} - W_{GO}$$

$$W_{CF} = W_{FM} - W_{XF} - W_{GF}$$

$$W_{XO} = 0.8 \text{ lb/sec}$$

$$W_{XF} = 1.8 \text{ lb/sec}$$

$$W_{GO} = W_T - W_{GF}$$

$$W_{GF} = \frac{W_T}{1 + r_G}$$

$$W_T = \frac{P_{TIF}\, A_{TIF}\, K_7}{TC^*_{TIF}}$$

$$K_7 = 32.174$$

$$W_C = W_{CO} + W_{CF}$$

CHARACTERISTIC VELOCITY

Thrust Chamber

$$C^* = \frac{K_7\, P_c\, A_t}{W_C}$$

$$K_7 = 32.174$$

DEVELOPED PUMP HEAD

Flows are normalized by using the following inlet pressures, temperatures, and densities.

$$P_{IO} = 39 \text{ psia}$$

$$P_{IF} = 30 \text{ psia}$$

$$\rho_{IO} = 70.79 \text{ lb/ft}^3$$

$$\rho_{IF} = 4.40 \text{ lb/ft}^3$$

$$T_{IO} = -295.212\,°F$$

$$T_{IF} = -422.547\,°F$$

Oxidizer

$$H_O = K_4 \left(\frac{P_{OO}}{\rho_{OO}} - \frac{P_{IO}}{\rho_{IO}}\right)$$

$$K_4 = 144$$

$$\rho = \text{National Bureau of Standards Values f (P,T)}$$

Fuel

$$H_f = 778.16\,\Delta h_{OFIS}$$

$$\Delta h_{OFIS} = h_{OFIS} - h_{IF}$$

$$h_{OFIS} = f(P,T)$$

$$h_{IF} = f(P,T)$$

PUMP EFFICIENCIES

Fuel, Isentropic

$$\eta_f = \frac{h_{OFIS} - h_{IF}}{h_{OF} - h_{IF}}$$

$$h_{OF} = f(P_{OF}, T_{OF})$$

Oxidizer, Isentropic

$$\eta_O = \eta_{OC}\, Y_O$$

$$\eta_{OC} = K_{4O} \left(\frac{Q_{PO}}{N_O}\right)^2 + K_{5O} \left(\frac{Q_{PO}}{N_O}\right) + K_{6O}$$

$$K_{4O} = 5.0526$$

$$K_{5O} = 3.8611$$

$$K_{6O} = 0.0733$$

$$Y_O = 1.000$$

TURBINES

Oxidizer, Efficiency

$$\eta_{TO} = \frac{B_{TO}}{B_{ITO}}$$

$$B_{TO} = K_5 \frac{W_{PO} \; H_O}{\eta_O}$$

$$K_5 = 0.001818$$

$$W_{PO} = W_{OM} + W_{PUVO}$$

$$W_{PUVO} = \sqrt{\frac{Z_{PUVO} \; \rho_{OO}}{R_v}}$$

$$Z_{PUVO} = A + B \, (P_{OO})$$

$$A = -1597$$

$$B = 2.3828$$

$$\text{IF } P_{OO} \geq 1010 \text{ Set } P_{OO} = 1010$$

$$\ln R = A_3 + B_3 (\theta_{PUVO}) + C (\theta_{PUVO})^3 + D_3 (e)^{\frac{\theta_{PUVO}}{7}} + E_3 (\theta_{PUVO}) (e)^{\frac{\theta_{PUVO}}{7}} + F_3 \left[(e)^{\frac{\theta_{PUVO}}{7}} \right]^2$$

$$A_3 = 5.5659 \times 10^{-1}$$

$$B_3 = 1.4997 \times 10^{-2}$$

$$C_3 = 7.9413 \times 10^{-6}$$

$$D_3 = 1.2343$$

$$E_3 = -7.2554 \times 10^{-2}$$

$$F_3 = 5.0691 \times 10^{-2}$$

Fuel, Efficiency

$$\eta_{TF} = \frac{B_{TF}}{B_{ITF}}$$

$$B_{ITF} = K_{10} \, \Delta h_f \; W_T$$

$$\Delta h_f = h_{TIF} - h_{TEF}$$

$$B_{TF} = B_{PF} = K_5 \left(\frac{W_{PF} \; H_f}{\eta_f} \right)$$

$$W_{PF} = W_{FM}$$

$$K_{10} = 1.4148$$

$$K_5 = 0.001818$$

Oxidizer, Developed Horsepower

$$B_{TO} = B_{PO} + K_{56}$$

$$B_{PO} = K_5 \frac{W_{PO}\, H_O}{\eta_O}$$

$$K_{56} = -15$$

Fuel, Developed Horsepower

$$B_{TF} = B_{PF}$$

$$B_{PF} = K_5 \frac{W_{PF}\, H_f}{\eta_f}$$

$$W_{PF} = W_{FM}$$

Fuel, Weight Flow

$$W_{TF} = W_T$$

Oxidizer Weight Flow

$$W_{TO} = W_T - W_B$$

$$W_B = \left[\frac{2K_7 \quad H_2}{\gamma_{H2}-1} (P_{RNC})^{\frac{2}{\gamma_{H2}}} \right]^{1/2} \left[1 - (P_{RNC})^{\frac{\gamma_{H2}-1}{\gamma_{H2}}} \right] \frac{A_{NB}\; P_{BNI}}{(R_{H2} T_{BIR})^{1/2}}$$

$$P_{RNC} = f\,(\beta_{NB}, \gamma_{H2})$$

$$\beta_{NB} = \frac{D_{NB}}{D_B}$$

$$\gamma_{H2}, M_{H2} = f(T_{H2R}, R_G)$$

$$A_{NB} = K_{13}\, D_{NB}$$

$$K_{13} = 0.7854$$

$$T_{BIR} = T_{TIO} + 460$$

$$P_{BNI} = P_{TEFS}$$

P_{TEFS} = Iteration of P_{TEF}

$$P_{TEF} = P_{TEFS} \left[1 - K_8 \left(\frac{W_T}{P_{TEFS}} \right)^2 \frac{T_{H2R}}{D^4{}_{TEF}\, M_{H2}} \left(\frac{\gamma_{H2}-1}{\gamma_{H2}} \right) \right]^{\frac{\gamma_{H2}}{\gamma_{H2}-1}}$$

$$K_8 = 38.8983$$

GAS GENERATOR

Mixture Ratio

$$r_G = D_1 (T_{H1})^3 + C_1 (T_{H1})^2 + B_1 (T_{H1}) + A_1$$

$$A_1 = 0.2575$$

$$B_1 = 5.586 \times 10^{-4}$$

$$C_1 = -5.332 \times 10^{-9}$$

$$D_1 = 1.1312 \times 10^{-11}$$

$$T_{H1} = T_{TIFM}$$

Flows

$$TC^*_{TIF} = D_2 (T_{H1})^3 + C_2 (T_{H1})^2 + B_2 (T_{H1}) - A_2$$

$$A_2 = 4.4226 \times 10^3$$

$$B_2 = 3.2267$$

$$C_2 = -1.3790 \times 10^{-3}$$

$$D_2 = 2.6212 \times 10^{-7}$$

$$P_{TIF} = P_{TIFS} \left[1 + K_8 \left(\frac{W_T}{P_{TIFS}} \right)^2 \frac{T_{HIR}}{D^4_{TIF} M_{H1}} \frac{\gamma_{H1} - 1}{\gamma_{H1}} \right]^{\frac{\gamma_{H1}}{\gamma_{H1} - 1}}$$

$$K_8 = 38.8983$$

Note: P_{TIF} is determined by iteration.

$$T_{HIR} = T_{TIF}$$

$$M_{H1}, \gamma_{H1}, C_p, r_{H1} = f\,(T_{HIR}, r_G)$$

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13. ABSTRACT

Five firings of the Rocketdyne J-2 rocket engine were conducted in Test Cell J-4 of the Large Rocket Facility. The firings were accomplished during test period J4-1801-20 at pressure altitudes ranging from 104,000 to 112,000 ft at engine start to evaluate engine starting characteristics at the minimum main oxidizer valve sequence ramp limit and reduced fuel pump net positive suction head. These firings were in support of the S-II vehicle application for Saturn flights AS 502 and AS 503. Engine components were thermally conditioned to predicted values for the S-II interstage/engine environment. Satisfactory engine operation was obtained. The accumulated firing duration was 56.22 sec.

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1. Rocket motors -- J-2

2 " " -- Performance

3 " " -- Starting

4 " " -- Ignition

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